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## W. B. WRAGGE, B.Sc. (Tech.), F.I.M., A.R.I.C.

WILLIAM BENJAMIN WRAGGE was born and educated in Manchester. He received his technical education at Manchester University, where he took an Honours Course in Chemistry at the Faculty of Technology. He was awarded the degree of B.Sc. (Tech.), specializing in metallurgy, in 1924.

He took up his first appointment in the new Laboratory of the Executors of James Mills Limited in 1925. Later he became Chief Metallurgist, and in 1943 he was appointed to the Board of Executors. In 1940 he became a Director of Ledloy Limited; he was appointed Managing Director in 1946, and Chairman of the Company in 1953. He has also been a Director of Bredbury Mills since 1951.

Mr. Wragge was President of the Manchester Metallurgical Society for the session 1953–54. He was elected a Member of The Iron and Steel Institute in 1941.

W. B. Wragge, B.Sc. (Tech.), F.I.M., A.R.I.C.
Honorary Member of Council, 1953–54

# PROCEEDINGS OF THE INSTITUTE

REPORTS OF COUNCIL - OFFICIAL NOTICES

## SPECIAL MEETING IN SWEDEN, 1954

**A Special Meeting of The Iron and Steel Institute was held in Sweden from Monday, 7th June, to Friday, 18th June, 1954, by invitation of the President and Council of Jernkontoret.**

**The Programme included visits to works in the neighbourhood of Gothenburg and Västerås, a period in Stockholm, and three alternative tours to the steelmaking and ore mining areas. A Joint Technical Session was held with Jernkontoret at Riksdagshuset, Stockholm, on Saturday, 12th June. Members of the Institute were also able to attend the Technical Meeting of Jernkontoret, held at Riksdagshuset on Friday, 11th June. A number of social functions were arranged, as well as a full programme of excursions for the Ladies.**

### ORGANIZATION

The Council of Jernkontoret (President, Mr. Evert Wijkander) were the hosts for the meeting. The detailed arrangements were in the hands of Mr. G. Frisell, formerly Managing Director and a Member of Council of Jernkontoret. A Ladies' Committee, with Mrs. Wijkander at the head, took charge of the entertainment of the ladies.

A short history of Jernkontoret, with biographies of some prominent officials, was given on pp. 193–196 of the May issue of the *Journal*.

### TECHNICAL SESSIONS

A Joint Technical Session with Jernkontoret was held on Saturday, 12th June, at Riksdagshuset, Stockholm. This is the distinguished building in which the Swedish Parliament holds its meetings. The beautiful circular hall used by the second chamber—the equivalent of the House of Commons—is equipped with comfortable desks, the latest devices for amplifying speech and hearing, and electrical machinery for the mechanical recording of debates.

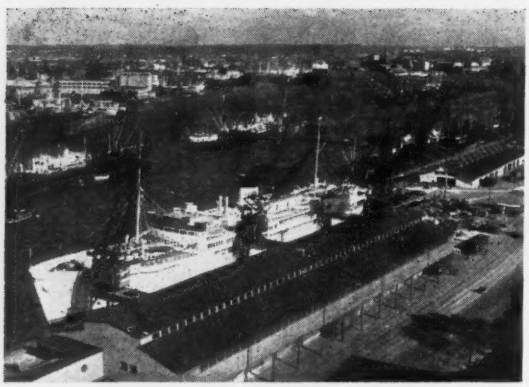
Important Swedish and British papers on pelletizing were presented and discussed, including one by Dr. Magnus Tigerschiöld, formerly Director of Research of Jernkontoret, and now Director of Metallurgical Research and Development with Trafikaktiebolaget Grangesberg-Oxelosund and Luossavaara-Kiirunavaara A.B., a Bessemer Medallist of 1947, and two by authors on the staffs of the British Iron and Steel Research Association and Stewarts and Lloyds Ltd. This, the chief feature of the Meeting, was followed by the brief presentation of a joint paper on the application of the system of the Universal Decimal Classification to the literature of the steel industry. The paper, apart from its intrinsic value, is memorable since it is, as far as is known, the only paper written jointly by officials of Jernkontoret and the Institute, and the only paper on methods of classifying technical literature published by these Societies.

The proceedings concluded with a discussion on an interesting series of British and Swedish papers on the properties of certain iron alloys of high purity. A report on the meeting will be published later in the year.

Members were also invited to take part in the Technical Meeting of Jernkontoret. The papers discussed on that occasion, together with others especially prepared for the Swedish Meeting, some of which were presented at the Institute's Annual General Meeting in London, in May, were published in the April and May issues of the *Journal* and in *Jernkontorets Annaler*.

### THE SWEDISH IRON AND STEEL INDUSTRY

Sweden has for long been one of the major iron-producing countries in Europe. Her industry developed early, and by the middle of the eighteenth century she was producing 40% of the world's production of iron. Since the development of mass-production methods of steelmaking during the last century, she has been far outstripped in tonnage by other countries, so that her production of steel is now only 1% of the world total, although the actual amount now produced is about twenty times as great as it was 200 years ago. Sweden possesses three natural resources in great abundance—rich iron ore, forests, and water. These have enabled her to maintain her position as a major quality-steel-producing nation to the present day. With the introduction of electric power and its application to ironmaking, great hydro-electric schemes were initiated to harness



**Gothenburg: The Harbour**

the abundant waters of Sweden's many rivers, thereby offsetting to some extent the disadvantage of having no substantial supplies of coking coal.

The Swedish iron and steel industry specializes in high-grade and alloy steels, and these are exported to over sixty countries. The whole of the production of mild steel is used for home consumption and has to be supplemented by imports. With a few exceptions, iron and steel production is concentrated in Central Sweden, largely in the provinces of Värmland and Dalecarlia. The local iron-ore resources of these districts are still important, although the production is now far less than in Lapland, where the rich iron ore deposits of Kiruna and Malmberget (Gällivare) produce the largest output of high-grade ore in Europe. The Institute's Meeting was designed to enable Members to visit these areas, as well as the industries of Gothenburg and Stockholm.

No attempt is made in this short record to provide technical descriptions of the works and mines, or accounts of the interesting processes operated, or of recent technical and scientific developments. Many of these have been referred to in papers already published, and it is hoped that as further opportunities occur, additional information will be provided in papers in the *Journal*.

## GOTHENBURG

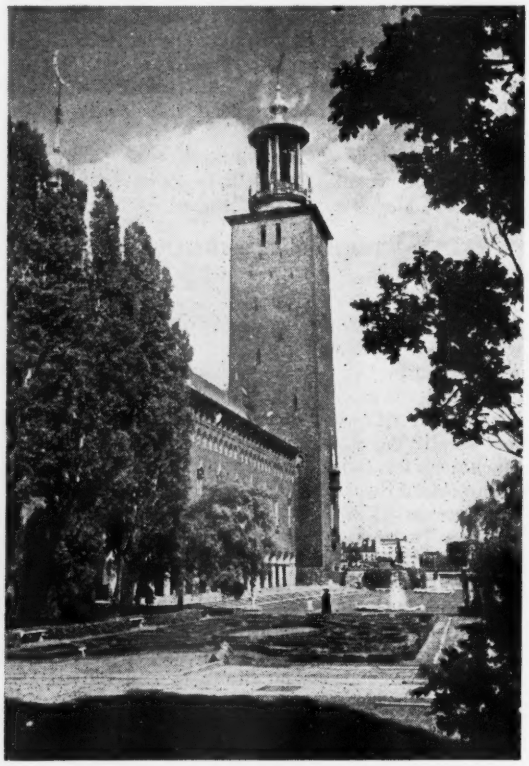
The Meeting began on 7th June, with a programme of visits in Gothenburg. Visits were made to the ferro-alloys plant of A.B. Ferrolegeringar, to the ball-bearing works of A.B. Svenska Kullagerfabriken, to the factories of A.B. Volvo, pioneers of the Swedish motor-car industry, and to the old-established shipyards of A.B. Götaverken. Members were entertained to luncheon by the Swedish Lloyd Steamship Co., Ltd., at Långedrag—a delightful restaurant on the sea—and to dinner by local industrialists in the fine halls of Börsen.

## VÄSTERÅS

Many members travelled by special train from Gothenburg to Västerås, a metallurgical centre north-east of Stockholm. Here visits were made to the works of A.B. Svenska Metallverken, which makes a wide variety of non-ferrous products, to the steelworks of Surahammars Bruks A.B., producing high-grade steels of all types for the electrical industry, and to the works of ASEA (Swedish General Electric Company), which manufactures, in addition to a wide range of heavy electrical equipment, arc and high-frequency furnaces. Members and Ladies were very hospitably received. They obtained lasting memories, not only of the efficiency of Swedish industry but also of the charm of Swedish hospitality, and these were later strengthened by experience in Stockholm and on final excursions to industrial districts.

## STOCKHOLM

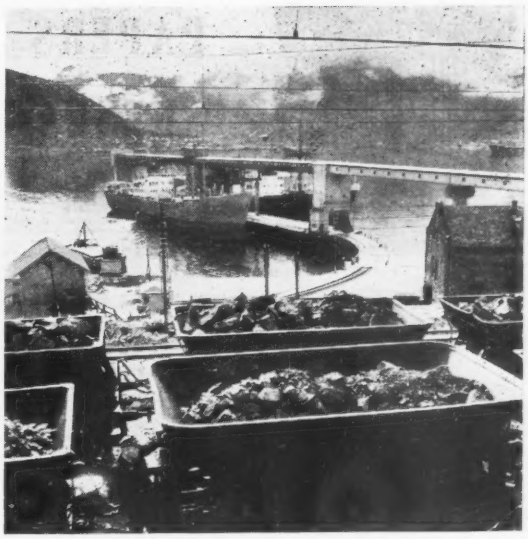
The second part of the Meeting was held in Stockholm. Here the programme was very varied; in addition to the technical sessions with Jernkontoret, there were works visits and social functions. The works visited included A.B. Atlas Diesel, A.B. Svenska Gasaccumulator (AGA), the L. M. Ericsson Telephone Company, and the Swedish Diamond Rock Drilling Company. Visits were also made to the Technical Museum, the Royal Institute of Technology, and the Institute for Metal Research. The three evening parties at which Members and Ladies were the guests of Jernkontoret were outstanding. On 10th June, the President and Council of Jernkontoret held a reception and cocktail party to welcome the Institute in the reception rooms of Jernkontoret's building. On the following evening there was a special performance at the Royal Opera House; the programme consisted of



**Stockholm: Stadshuset (the Town Hall)**

Act III of *The Marriage of Figaro* (Mozart), Act II of *Swan Lake* (Tchaikowsky), and the Triumph Scene from *Aidà* (Verdi). The performances were excellent, the scene was gay, and in the intervals members could meet old and make new friends. The final function in Stockholm was a banquet and dance by invitation of Jernkontoret at the Town Hall—one of the outstanding architectural triumphs of the modern world. The Institute was welcomed to Sweden by the President of Jernkontoret, and the President of the Institute, the Hon. R. G. Lyttelton, expressed the thanks of all those present for the sincere friendliness with which they had been received.

During the stay in Stockholm the Ladies, in addition to other visits, drove to Drottningholm, where a short special performance had been arranged for them in the eighteenth century theatre. On the Sunday, Members and Ladies were able to visit the University and Cathedral City of Uppsala, Sigtuna, and the old castle at Skokloster on Lake Mälaren. At the end of the Stockholm section of the Meeting, Members left on three special train excursions. Two excursions to Värmland and Dalecarlia, respectively, covered Central Sweden, and the third was to Lapland.



**Narvik: The new ore unloading pier**

## VÄRMLAND

The Värmland area gives several examples of an organization peculiar to the Swedish industry—a combination of iron and steel manufacture, forestry, electric-power production, and farming. Almost all the steelworks visited owned forests, with pulp plants and paper mills, and their own power stations. Thus the Uddeholms A.B. group, which was visited, includes the Hagfors iron and steelworks, the Storfors tube works, the Persberg mines (which have been worked since the fifteenth century), and the Skoghall sawmills and pulp plants. Visits were also made to the Hellefors Iron and Steel Works and the Bångbro rolling mills, and to the works of A.B. Bofors. The latter is best known as a manufacturer of armaments, and Members visited their steelworks, heat-treatment departments, engineering workshops, and proving ground.

## DALECARLIA

The excursion to Dalecarlia consisted principally of visits to plants of Sandvikens Jernverks A.B., Stora Kopparbergs Bergslags A.B., including the iron and steel works at Domnarfvet, and Fagersta Bruks A.B. The Stora Kopparberg company originated in the Middle Ages at Falun at the 'Great Copper Mountain' from which it takes its name. During the seventeenth century this mine contributed much to the wealth and military power of Sweden. Later the company included iron and steel manufacture in its interests, and it also owns the pulp and saw mills at Skutskär. All the works in this area can trace their history back to the Middle Ages, except Sandviken, which was founded in the 1860's to exploit the Bessemer process.

## LAPLAND

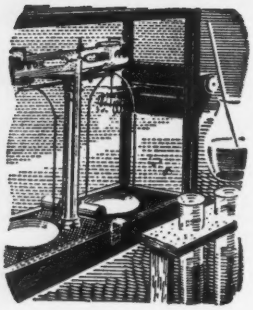
The third excursion took members north of the Arctic Circle. The finest Swedish iron ore comes from the far North, the most famous being that from Kiruna. Visits were made to the mines at the great twin iron mountains of Kiirunavaara and Luossavaara, and to that at Malmberget (Gällivare); and also to the ice-free port of Narvik in Norway, from where most of the ore is shipped.

A tremendous amount of development has been carried out by this Company. Mining at Kiruna is being changed over from open-cast to underground, and new crushing and classifying plants are being installed. The ore-loading installations at Narvik are being completely rebuilt so that efficient use can be made of the Company's new fleet of ore-carrying ships. A new pelletizing plant is being built.

After leaving the ore-fields, visits were paid to the state-built Norrbottens Järnverk A.B. at Luleå, now in the final stages of completion, and to the Bolidens Gruv A.B. smelting works at Rönnskär and the Boliden mine and concentration plant, which produce a large annual tonnage of non-ferrous and precious metals.

**The completion of the three special train excursions marked the end of a meeting of outstanding interest. Members who took part were deeply impressed by the high technical standard of the works they saw, and all those who attended took away with them lasting memories of great kindness, abundant hospitality, and sincere friendship.**

**The President and Council of the Institute wish to express their thanks to those without whose help the Meeting could not have been successfully carried out, and especially to the President and Council of Jernkontoret, Mr. G. Frisell, the Chairman and Members of the Ladies Committee, the Swedish State Railways and the Swedish Lloyd Steamship Company, Ltd., the Chairmen and Directors of the works and other establishments who invited Members to visit them, the authors of papers presented at the Technical Meetings, and all others who so willingly collaborated in organizing the Meeting.**



PAPERS AND REPORTS ON RESEARCH AND PRACTICE

METALLURGY · PLANT OPERATIONS · RESEARCH

# Sulphur in Silicate and Aluminate Slags

*By F. D. Richardson and C. J. B. Fincham*

SYNOPSIS

A study has been made of the partition of sulphur between gases containing sulphur and oxygen at controlled partial pressures, and molten silicates, aluminates, and iron- and steel-making slags. The results show that when $pO_2$ is less than $10^{-5}$–$10^{-6}$ atm., the sulphur in a slag is held entirely as sulphide, its concentration being controlled by the equilibrium $\frac{1}{2}S_2 + (O)_{melt} = \frac{1}{2}O_2 + (S)_{melt}$. When $pO_2$ is greater than $10^{-3}$–$10^{-4}$ atm. the sulphur is held almost entirely as sulphate and the equilibrium is $\frac{1}{2}S_2 + \frac{3}{2}O_2 + (O)_{melt} = (SO_4)_{melt}$. Between these limits both sulphide and sulphate must be present. The capacity of a melt to hold sulphur as sulphide is expressed as its sulphide capacity, $C_S = (\text{wt.-\% S in slag})(pO_2)^{\frac{1}{2}}/(pS_2)^{\frac{1}{2}}$, and the influence of slag composition on this capacity is considered. The results are discussed in relation to desulphurization in iron and steel making. They are applied to the transfer of sulphur between gas and slag in the open hearth, to the desulphurization of blast-furnace slag, and to the possibility of making elemental sulphur from blast-furnace slag in a single-stage process. 923

THE behaviour of sulphur in slags has been the object of numerous investigations. The slag mixtures studied have usually been complex and the method adopted has almost without exception been measurement of the distribution of sulphur between a molten slag and molten iron. With such a method it is not possible to distinguish satisfactorily the separate effects of slag composition and oxygen potential on the sulphur partition. This is because the iron oxide content of the slag, and hence the slag composition, varies as the oxygen content of the metal (or more broadly, the oxygen potential) is changed.

To avoid this difficulty the authors have recently made a study of the partition of sulphur between flowing gases of controlled oxygen and sulphur potentials and various silicate and aluminate slags at temperatures between 1450° and 1650° C. Small samples of slag were brought into equilibrium with gas mixtures made from $H_2$, $CO_2$, $SO_2$, and $N_2$, in such proportions as to give the required partial pressures of sulphur and oxygen when raised to the temperatures of the melts. These partial pressures were calculated from the available thermodynamic data on the various gaseous species which are present in significant amounts at the equilibrium temperatures, *i.e.*, $SO_3$, $SO_2$, SO, S, $S_2$, CS, $CS_2$, COS, $H_2$, HS, $H_2S$, $H_2O$, CO, $CO_2$, $N_2$, $O_2$. Those slags which contained only lime, magnesia, alumina or silica were held in inert platinum cups so that their compositions were independent of the oxygen and sulphur potentials in the gas mixtures, apart of course from the small amount of sulphur (0·01 to 1·0%) which was taken up. Even with the iron-oxide–silica mixtures, which had to be held in silica cups, the content of ferric iron and the '$FeO$'/$SiO_2$ ratio were not far from being constant over the range of conditions studied.

A full report on this investigation, dealing mainly with theoretical aspects, has already been made elsewhere,[19] for the results are of interest to the chemist and geologist as well as to the metallurgist. The purpose of this paper is to describe the main findings and to consider them in relation to processes involving sulphur in iron and steel making.

Paper CP/17/2 of the Chemistry Department of the British Iron and Steel Research Association, received 24th December, 1953.

Dr. Richardson is Head of the Nuffield Research Group in Extraction Metallurgy at the Royal School of Mines. Dr. Fincham, formerly with B.I.S.R.A., is now Research Associate at the School of Mines, Columbia University, New York.

## SULPHIDE AND SULPHATE EQUILIBRIA

### Slags without Iron Oxides

The compositions of the slags investigated are shown in Table I. The last two columns give the sulphide and sulphate capacities which were derived from the measurements and are referred to later.

The results have shown[19] that in $CaO$–$SiO_2$, $CaO$–$Al_2O_3$, and $CaO$–$SiO_2$–$Al_2O_3$ melts the sulphur content is controlled by two equilibria which can be represented by the equations:

## Table I

### COMPOSITIONS OF SLAGS

| Number | Composition,* wt.-% C | A | S | Mole Ratios* C : A : S | Melting Point, °C. | Capacities $C_S$ | $C_{SO_4}$ |
|---|---|---|---|---|---|---|---|
| | | | | | | At 1500° C. | |
| S1 | 37 | 27 | 36 | 1·1 : 0·44 : 1 | 1425 | $1·3 \times 10^{-4}$ | $5·0 \times 10^{6}$ |
| S2 | 32·5 | 26·5 | 41 | 0·85 : 0·38 : 1 | 1400 | 0·84 | 3·2 |
| S4 | 54 | 1 | 45 | 1·3 : 0·01 : 1 | 1480 | 2·5 | 15·0 |
| S5 | 41 | 52 | 7 | 6·2 : 4·3 : 1 | 1450 | 16·0 | 67·0 |
| S6 | 45·8 | 18 | 36·2 | 1·35 : 0·3 : 1 | 1400 | 3·7 | 16·0 |
| S1a | 36 | 27·5 | 36·5 | 1·05 : 0·44 : 1 | 1425 | 0·96 | — |
| | | | | C : S | | At 1650° C. | |
| S11 | 54 | — | 46 | 1·26 : 1 | 1460 | $7·1 \times 10^{-4}$ | $0·23 \times 10^{6}$ |
| S12 | 48 | — | 52 | 1·00 : 1 | 1540 | 3·6 | 0·17 |
| S13 | 37 | — | 63 | 0·63 : 1 | 1440 | 2·1 | — |
| | | | | C : A | | | |
| S14 | 35·5 | 64·5 | — | 1·00 : 1 | 1600 | 9·6 | 0·29 |
| S15 | 41 | 39 | — | 1·27 : 1 | 1540 | 21·0 | 0·58 |
| S16 | 52·5 | 47·5 | — | 2·0 : 1 | 1460 | 94·0 | 3·5 |
| | M | | S | M : S | | | |
| S17 | 40 | — | 60 | 1·00 : 1 | 1600 | 1·2 | 0·06 |

* C = CaO, A = $Al_2O_3$, S = $SiO_2$, M = MgO

$$\tfrac{1}{2}S_2 + (O)_{melt} = \tfrac{1}{2}O_2 + (S)_{melt} \quad \ldots\ldots(1)$$

$$K_1 = \frac{(S)(pO_2)^{\frac{1}{2}}}{(O)(pS_2)^{\frac{1}{2}}}$$

$$\tfrac{1}{2}S_2 + \tfrac{3}{2}O_2 + (O)_{melt} = (SO_4)_{melt} \quad \ldots\ldots(2)$$

$$K_2 = \frac{(SO_4)}{(pS_2)^{\frac{1}{2}}(pO_2)^{\frac{1}{2}}(O)}$$

Although (O) is unknown, it is constant at constant slag composition, so that

$$K_1' = \frac{(S)(pO_2)^{\frac{1}{2}}}{(pS_2)^{\frac{1}{2}}} \propto K_1 ;$$

$$K_2' = \frac{(SO_4)}{(pS_2)^{\frac{1}{2}}(pO_2)^{\frac{3}{2}}} \propto K_2 \quad \ldots(3)$$

These equilibria operate simultaneously, but only the former—the sulphide equilibrium—is of importance at oxygen pressures $< 10^{-5}$–$10^{-6}$ atm., and only the latter—the sulphate equilibrium—is of importance at oxygen pressures $> 10^{-3}$–$10^{-4}$ atm. Under the former conditions the sulphur content of the melt at a constant sulphur content of the gas is decreased by increasing $pO_2$; under the latter conditions it is increased by increasing $pO_2$. The result of these two opposing effects is that the sulphur content of a slag in equilibrium with a gas of constant sulphur content has a minimum at an oxygen partial pressure of about $10^{-4}$–$10^{-5}$ atm., depending on the temperature.

The interplay of these two equilibria under different conditions is shown clearly in Figs. 1*a*, 1*b*, 2, and 3, which represent some of the authors' results. The '$SO_2$ input' referred to in these diagrams is the volume per cent. of $SO_2$ present in the ingoing gas mixture ($H_2$, $CO_2$, $SO_2$, $N_2$). Digits against individual points indicate the number of samples on which they are based. Where no digits are shown, the number of samples is two, both from the same experiment. The digit 2 is shown where the two samples come from different experiments. The spread in values is less

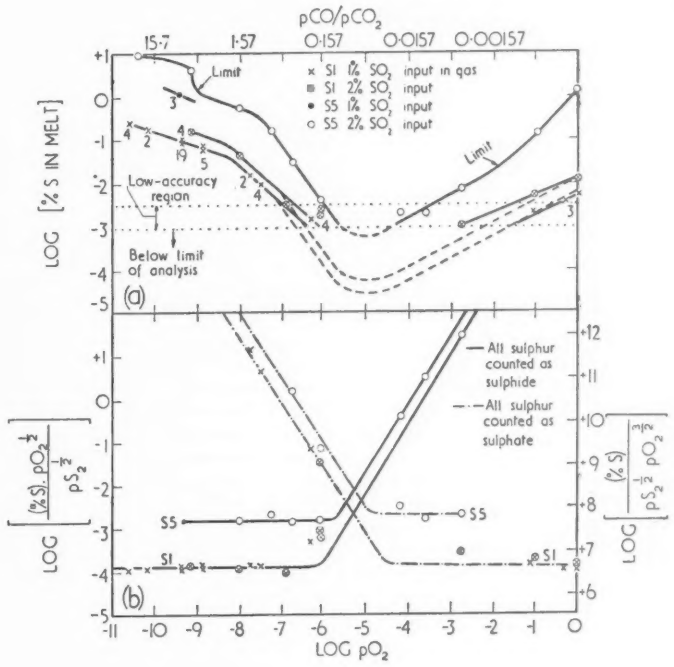



**Fig. 1—(*a*) Sulphur equilibria at 1500° C.; (*b*) sulphide and sulphate equilibrium constants and the ranges of oxygen pressure over which they hold**

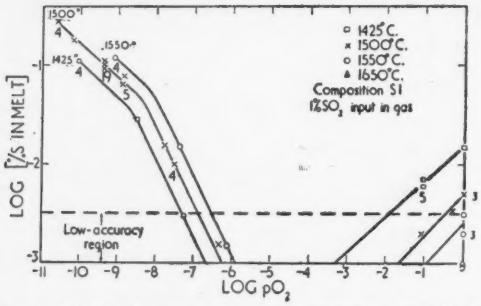



**Fig. 2—Effect of temperature on sulphur equilibria**

than either the size or the spread of the plotted points.

The limits marked for slag S5 at 2% $SO_2$ input in Fig. 1*a* are of interest. The limit at an oxygen pressure of $10^{-9}$ atm. is the point at which the slag S5 becomes saturated with calcium sulphide. Anomalously high sulphur contents are obtained at lower oxygen pressures owing to the separation of free calcium sulphide. The limit at an oxygen pressure of $10^{-2.5}$ represents the conditions at which the formation of pyrosulphate ($S_2O_7$) becomes significant. At lower $SO_2$ inputs or at higher temperatures this is not important. The equilibrium constants $K_1'$ and $K_2'$ hold well within these limits for S5 at 2% input of $SO_2$ and for S1 at 1% and 2% $SO_2$ over the whole range of the measurements. This is brought out in Fig. 1*b* where the points and log $pO_2$ scale correspond exactly with those in Fig. 1*a*. The broken lines in Fig. 1*a* show the sulphur contents calculated from the values of $K_1'$ and $K_2'$ for these slags, in the regions of low accuracy and below the limits of analysis. The scatter in the values of $K_2'$ (Fig. 1*b*) is to be expected as the sulphur contents in the sulphate region were small and the possible inaccuracies in analysis were significant in comparison with them. Plots similar to Fig. 1*b*, which have been made for the other ternary and binary slags studied (not shown here) confirm that similar equilibrium constants hold for them also.

Because the equilibria represented by equations (1) and (2) adequately account for the sulphur contents of the slags investigated, it follows that:

(i) The activity of replaceable oxygen in the melt is not significantly altered by the substitution of small amounts of sulphur

(ii) For the low concentrations of sulphur found in these experiments, the activities of (S) and ($SO_4$) are proportional to the sulphur concentrations.

The results in Fig. 1*a* for S1 at 1500° C. show that when the $SO_2$ input was doubled at constant $pO_2$, the percentage S in the melt was also approximately doubled under both the sulphide- and the sulphate-forming conditions. This should happen, if the activity coefficients of the sulphide and sulphate do not vary significantly over the range of sulphur concentrations studied, because, for a fixed value of $pO_2$, $(pS_2)^{\frac{1}{2}}$ is approximately proportional to the $SO_2$ input when the latter is small.

The changes in slopes of the curves in Fig. 1*a* at about $pO_2 = 10^{-8}$ atm. occur because the curves are plotted for constant percentage $SO_2$ input and not constant $pS_2$. At 1500° C., when $pO_2$ is less than about $10^{-8.5}$ atm., $pS_2$ is determined almost entirely by the equilibria between $H_2$, $S_2$, $H_2S$, and HS. When $pO_2$ is greater than $10^{-7.5}$ atm., $pS_2$ is determined almost entirely by the equilibria between $O_2$, $S_2$, $SO_2$, and SO. Between these two oxygen pressures there is a transition region in which the slope of the $pO_2/pS_2$ curve changes markedly.

The effect of temperature on the equilibria with mixture S1 is shown in Fig. 2. It is clear that at a constant $pO_2$ and a constant $SO_2$ input, raising the temperature *increases* the amount of *sulphide* sulphur present in the melt, but *decreases* the amount of sulphate. This is to be expected in view of the following heats of reaction*:

$$CaO_{(s)} + \tfrac{1}{2}S_2 = CaS_{(s)} + \tfrac{1}{2}O_2$$
$$\Delta H^\circ_{1700\text{–}2000^\circ\,K.} = 24 \text{ k.cal.} \quad \text{.....(4)}$$
$$CaO_{(s)} + \tfrac{1}{2}S_2 + \tfrac{3}{2}O_2 = CaSO_{4(s)}$$
$$\Delta H^\circ_{1700\text{–}2000^\circ\,K.} = -195 \text{ k.cal.} \quad \text{.....(5)}$$

It is of interest to consider how far the results on the ternary CaO–$SiO_2$–$Al_2O_3$ melts at 1500° C. (Figs. 1*a* and 2, etc.) can be extrapolated to much lower oxygen potentials, by use of the values of $K_1'$ obtained by the authors over the range $10^{-11}$ to $10^{-6}$ atm. of oxygen. Hatch and Chipman[9] have measured the sulphur contents of carbon-saturated iron brought into equilibrium with silicate melts containing sulphur, and carbon monoxide gas at 1 atm. pressure at 1500° C. (*i.e.*, $pO_2 = 10^{-15.72}$ atm.). Their slags contained considerable quantities of magnesia, and their metals between 0·5 and 7·25% of silicon. They found that their results could be represented by a series of contours on a ternary diagram, as shown by the full lines in Fig. 4. These are constant-concentration lines, representing the sulphur content of the

* The partial molar heats of solution of CaO, CaS, and $CaSO_4$ must also be taken into account. Their signs are such as to make the one slag reaction more endothermic than reaction (4) and the other less exothermic than reaction (5). Their magnitudes would have to be unreasonable to make the sulphate formation endothermic. The data on which the quoted $\Delta H^\circ$ values are based are given in the Appendix.

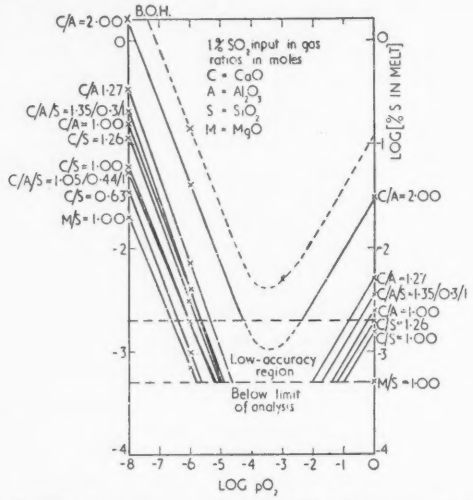



**Fig. 3—Effect of composition of melt on sulphur equilibria at 1650° C. B.O.H.—Basic open-hearth slag (*see* Table III)**

metal in equilibrium with 1·5% by weight of sulphur in the slag. The accuracy of these values is about ± 10%. By combination of the authors' values of $K_1'$ with the established thermodynamic data on the reactions $H_2 + \frac{1}{2}S_2 = H_2S$,[20] $H_2S = H_2 + [S]$,[25] $C + \frac{1}{2}O_2 = CO_2$,[24] and the data available on the influence of carbon and silicon on the behaviour of sulphur in molten iron,[17] it is possible to calculate the sulphur contents of carbon-saturated iron in equilibrium with 1·5% sulphur in the ternary slags of Table I.* The values so obtained are represented by the crosses in Fig. 4. There is reasonable agreement with the lines of Hatch and Chipman, particularly in view of the large amount of data involved in the calculation. It is to be expected that the authors' results should lead to rather lower concentrations of sulphur in the metal than those of Hatch and Chipman, for the latter had up to 19% by weight of magnesia in their slags, whereas only lime, silica, and alumina were present in the authors' mixtures. As Fig. 3 and also Fig. 5 show, magnesia is a less effective desulphurizing agent than lime. The agreement suggests that the chemistry of sulphur retention by a silicate slag at carbon saturation is the same as at much higher oxygen potentials. The possible existence of lower oxides of Si or Al, or of carbides, in such a slag thus has no important effect upon its sulphide capacity.

### Slags Containing Iron Oxides

It was not found possible to study iron-oxide–silica melts in iron cups because the slag crept out of them. Measurements were therefore made with such melts held in silica cups, *i.e.*, in equilibrium with silica. It was not possible to obtain satisfactory results with such mixtures at low oxygen pressures where the iron activity was high, apparently because of the formation of two phases: an Fe–FeS phase containing some ' FeO,' and an ' FeO '–$SiO_2$ phase containing some FeS. The appearance of the iron-rich phase was prevented by raising the oxygen pressure sufficiently to lower the iron activity to values less than about 0·03. This does not, according to Michal and Schuhmann,[16] markedly change the ' FeO '/$SiO_2$ ratio for the melt. The results obtained with these mixtures are shown in Table II.

It has not been conclusively shown that the same type of sulphide equilibrium holds for the ' FeO '–$SiO_2$ slags as has been proved to hold for the CaO–$SiO_2$, MgO–$SiO_2$, and CaO–$SiO_2$–$Al_2O_3$ slags, for measurements with the iron oxide mixtures were made only at one oxygen pressure at each of two temperatures. Nevertheless this supposition appears reasonable, because the thermodynamic properties $\gamma$(FeS) and $\Delta\overline{H}$(' FeO ') which can be calculated from the measurements made on the ' FeO '–$SiO_2$ melts on the assumption that equation (1) holds, are compatible with other knowledge of them.

The sulphide equilibrium was measured for three typical iron- and steel-making slags. The compositions and the results are given in Table III.

* The silicon contents of the metals in equilibrium with these slags were estimated approximately from the experimental results of Hatch and Chipman.

**Table II**

**RESULTS WITH ' FeO '–$SiO_2$ MIXTURES**

$pN_2$ = 0·50 atm.; $SO_3$ input, % = 0·3

| | | |
|---|---|---|
| Temperature, ° C. | 1350 | 1500 |
| $pH_2/pCO_2$ | 0·22 | 0·30 |
| $pO_2$, atm. | $1·13 \times 10^{-8}$ | $1·88 \times 10^{-7}$ |
| $pS_2$, atm. | $1·1 \times 10^{-5}$ | $1·8 \times 10^{-6}$ |
| FeO, wt.-% | 56·8 | 54 |
| $Fe_2O_3$, wt.-% | 4·5 | 4 |
| $SiO_2$, wt.-% | 38·7 | 42 |
| S, mean % | 0·066 | 0·017 |
| Scatter of results | ± 8% | ± 18% |
| Number of samples | 4 | 4 |

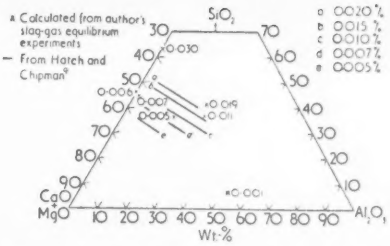



**Fig. 4—Sulphur contents, wt.-%, of carbon-saturated iron in equilibrium with CO at 1 atm. and CaO–$SiO_2$–$Al_2O_3$ slags containing 1·5% sulphur**

## SULPHUR CAPACITIES OF SLAGS

It is desirable to be able to compare the results obtained for melts of various compositions at the same temperature but at differing values of $pO_2$ and $pS_2$. This can be done by means of two functions which can usefully be termed the sulphide and sulphate capacities, and which depend only on melt composition and temperature.

The sulphide equilibria in the binary melts may be represented fully by the equations:

$$(CaO)_{melt} + \tfrac{1}{2}S_2 = (CaS)_{melt} + \tfrac{1}{2}O_2 \quad \ldots\ldots(6)$$

$$(MgO)_{melt} + \tfrac{1}{2}S_2 = (MgS)_{melt} + \tfrac{1}{2}O_2 \quad \ldots\ldots(7)$$

$$(\text{' FeO '})_{melt} + \tfrac{1}{2}S_2 = (\text{' FeS '})_{melt} + \tfrac{1}{2}O_2 \quad \ldots\ldots(8)$$

provided that no significant proportion of the sulphur held in the slag is linked to silicon or aluminium, as for example in $SiS_2$ or $Al_2S_3$. This condition must hold because, as will be seen later, sulphur becomes much less strongly held as the melts contain more silica or alumina.

The simplest definition of sulphide capacity would appear to be given by the quantity $(\%S)(pO_2)^{\frac{1}{2}}/(pS_2)^{\frac{1}{2}}$, measured under conditions where the sulphur is present only as sulphide, and hereafter referred to by the symbol $C_S$. This is more straightforward than the definition already proposed by Rosenqvist,[23] as it does not involve the equilibrium constants ($K_{MS}$) for the reactions $MS_{(s)} + \frac{1}{2}O_2 = MO_{(s)} + \frac{1}{2}S_2$. The quantity $C_S$ is directly measurable and can be used to compare widely differing mixtures, whether binary or more complex; $K_{MS}$ is accurately known only for CaS, and in complex mixtures (*e.g.*, CaO + MgO + ' FeO ' + $SiO_2$) it cannot at present be assigned any value at all. The sulphate capacity of a slag can similarly be defined as $(\%S)/(pS_2)^{\frac{1}{2}}(pO_2)^{\frac{3}{2}}$, measured under conditions where the sulphur is present only as sulphate. It is referred to as $C_{SO_4}$.

The authors' measurements have shown[19] that at oxygen pressures less than $10^{-5}$–$10^{-6}$ atm., $C_S$ is constant for a given temperature and composition

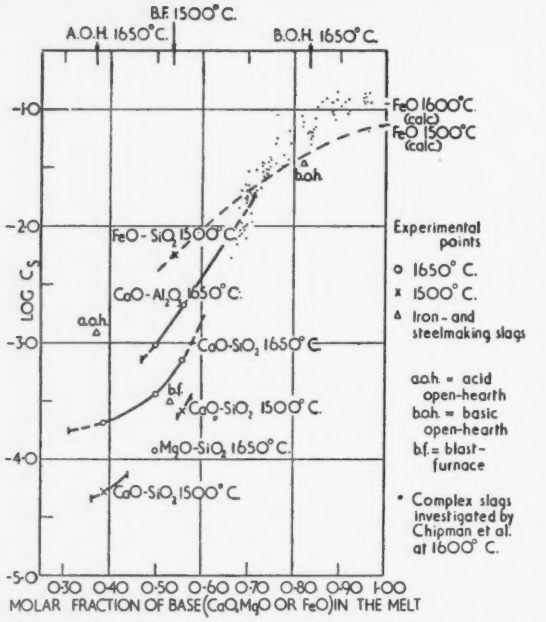



**Fig. 5—Sulphide capacities of various silicate and aluminate slags, with curves extended (broken lines) to cover full liquid ranges**

up to 1% S in the slag. Correspondingly, at oxygen pressures greater than about $10^{-3}$–$10^{-4}$ atm. $C_{SO_4}$ is constant up to at least 0·01% S. The ranges of oxygen pressures of main interest in iron and steel making are those which lie below the oxygen pressures corresponding to the Fe–'FeO' equilibrium, *i.e.*, $10^{-8\cdot0}$ atm. at 1650° C. and $10^{-9\cdot2}$ atm. at 1500° C. These are the conditions under which $C_S$ is constant.

### Sulphide Capacities of Binary Mixtures and Complex Slags

Figure 5 shows sulphide capacities at 1500° and 1650° C. plotted against the molar fraction of base (*i.e.*, CaO, MgO, or 'FeO') for the binary mixtures $CaO$–$SiO_2$, $CaO$–$Al_2O_3$, $MgO$–$SiO_2$, and 'FeO'–$SiO_2$. The sulphide capacities for pure liquid 'FeO' at 1500° and 1600° C. were calculated from the equilibrium constants (*see* Appendix) for the reaction

$$'FeS'_{(liq.)} + \tfrac{1}{2}O_2 = 'FeO'_{(liq.)} + \tfrac{1}{2}S_2 \quad \ldots\ldots\ldots (9)$$

and from the activity coefficient of FeS in very dilute solution in 'FeO,' which was calculated by Chipman[3] from the 'FeO'–FeS phase diagram and the heats of fusion of 'FeO' and FeS. It is reasonable to suppose that the sulphur capacities for 'FeO'–$SiO_2$ melts follow the broken curve joining the authors' value for 0·53 molar fraction of 'FeO,' to the value calculated for pure 'FeO.'

Log $C_S$ values for the O.H. and blast-furnace slags investigated are represented by triangular points in Fig. 5, the molar fractions indicated being values of $(N_{CaO} + N_{FeO} + N_{MgO} + N_{MnO})$ in each case.*

The large number of small points lying roughly on a curve in Fig. 5 represent the sulphur capacities calculated by the authors for the silicate melts used by Fetters and Chipman[7] and by Winkler and Chipman[29] in their studies of the partition of sulphur and oxygen between molten iron and slags at about 1600° C. Values of (%S)[O]/[S], obtained directly from their results for mixtures containing less than 5% $P_2O_5$ and less than 10% MnO by weight, were converted to values of $C_S$ by application of the available data on the equilibria $\frac{1}{2}O_2 = [O]$ (*see* Dastur and Chipman[6]) and $\frac{1}{2}S_2 = [S]$ (*see* Sherman, Elvander, and Chipman[25]).

* The sulphur capacity obtained by the authors for the basic O.H. slag described in Table III is lower by a factor of two than the values obtained for similar slags by Chipman *et al.* This is probably because the authors' measurement was made at an oxygen pressure of $10^{-6}$ atm. and those of Chipman *et al.* at about $10^{-8}$ atm. (*i.e.*, in equilibrium with molten iron). The proportion of the iron oxides and lime associated as ferrites will be higher under the former than under the latter conditions, so that the lime and ferrous oxide activities and hence $C_S$ will be correspondingly lowered.

**Table III**

**RESULTS WITH IRON- AND STEEL-MAKING SLAGS**

| Approximate Works' Analyses, wt.-% | | | | | | | | | | | Molar Fraction of Bases |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Slag | FeO | $SiO_2$ | $Al_2O_3$ | $TiO_2$ | MgO | MnO | CaO | $P_2O_5$ | $Cr_2O_3$ | $V_2O_5$ | |
| 1. Blast-furnace | 0·5 | 31·8 | 19·0 | 0·5 | 2·5 | 1·0 | 42·2 | — | — | — | 0·53 |
| 2. Acid O.H. | 12 | 56 | — | — | — | 15 | 9 | — | — | — | 0·37 |
| 3. Basic O.H. | 14·8 | 8·1 | 1·2 | 0·5 | 6·0 | 3·4 | 48·4* | 14·2 | 0·4 | 1·0 | 0·83 |

| Partial Pressures and Sulphur Capacities† | | | | | |
|---|---|---|---|---|---|
| | Temp., ° C. | $pO_2$ | $pS_2$ | S, % | $C_S$, wt.-% |
| 1. Blast-furnace | 1500 | $10^{-9\cdot37}$ | $10^{-3\cdot60}$ | 0·298 | $3\cdot9 \times 10^{-4}$ |
| | 1650 | $10^{-6\cdot0}$ | $10^{-4\cdot80}$ | 0·006 | 15 |
| | 1650 | $10^{-8\cdot0}$ | $10^{-3\cdot57}$ | 0·195 | 12 |
| 2. Acid O.H. | 1650 | $10^{-6\cdot0}$ | $10^{-4\cdot80}$ | 0·005 | 12 |
| 3. Basic O.H.‡ | 1650 | $10^{-6\cdot0}$ | $10^{-4\cdot80}$ | 0·138 | 345 |
| | 1650 | $10^{-3\cdot0}$ | $10^{-9\cdot48}$ | 0·010 | mainly sulphate |

* Molar fraction of CaO = 0·57 † See next section

‡ Measurements were not made at oxygen pressures less than $10^{-6}$ because too much iron would have been reduced into the platinum cups. Measurements were not made at oxygen pressures greater than $10^{-3}$, because the slag then crept out of the cups

These slags were complex mixtures of CaO, MgO, MnO, FeO, $SiO_2$, $Al_2O_3$, $P_2O_5$, and $Fe_2O_3$. The molar fraction of base required for plotting their $C_S$ values in Fig. 5 was taken as $N_{CaO} + N_{MgO} + N_{MnO} + N_{FeO}$, the remaining oxides being classed as 'acid.'

It has been shown elsewhere[19] that the $C_S$ values for the binary melts shown in Fig. 5 increase as the metal-oxide activities increase. The reason why the $C_S$ value obtained for the FeO–$SiO_2$ mixture (53 molar fraction of base) is so much greater (26 times) than that for the corresponding CaO–$SiO_2$ mixture lies, in the main, in the much higher value of the metal-oxide activity in the FeO–$SiO_2$ melt. At 1500° C., $a$('FeO')$_{(liq.)}$ at 0·54 molar is equal to 0·39 whereas $a(CaO)_{(s)}$ at 0·56 molar is about 0·014. There is hardly any difference between the equilibrium constants (*see* Appendix) for the two pure phase reactions

$$CaO_{(s)} + \tfrac{1}{2}S_2 = CaS_{(s)} + \tfrac{1}{2}O_2 \quad \ldots\ldots(10)$$
$$K_{10} = 2{\cdot}27 \times 10^{-3} \ (1500^\circ \text{ C.})$$

$$\text{'FeO'}_{(liq.)} + \tfrac{1}{2}S_2 = \text{'FeS'}_{(liq.)} + \tfrac{1}{2}S_2 \quad \ldots\ldots(11)$$
$$K_{11} = 2{\cdot}5 \times 10^{-3} \ (1500^\circ \text{ C.})$$

The only other factor which can contribute to the 26-times factor is the ratio of $\gamma$('FeS')$_{(liq.)}$ to $\gamma(CaS)_{(s)}$, and this is not likely to be much greater than two.[19]

The equilibrium constant for the reaction (*see* Appendix)

$$MgO + \tfrac{1}{2}S_2 = MgS + \tfrac{1}{2}O_2 \quad \ldots\ldots(12)$$
$$K_{12} = 4{\cdot}0 \times 10^{-5} \ (1650^\circ \text{ C.})$$

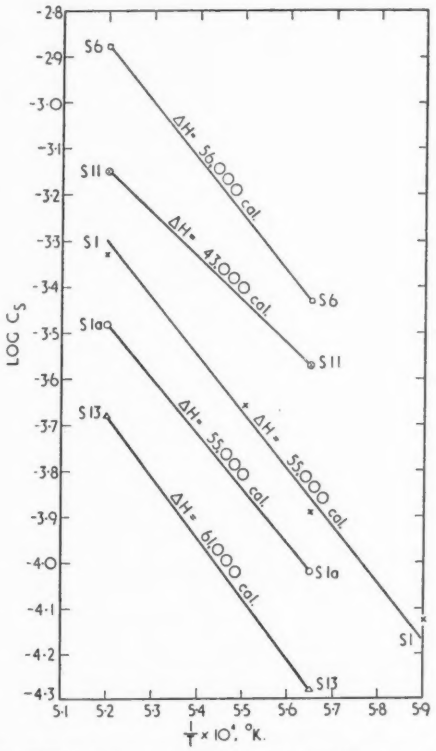



**Fig. 6—Effect of temperature on the sulphur capacities of slags**

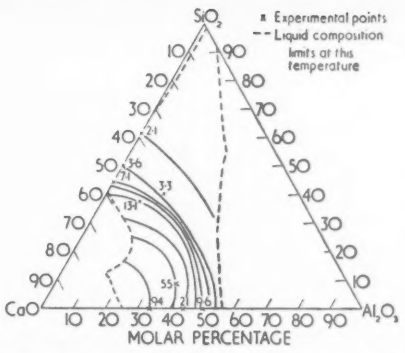



**Fig. 7—Sulphide capacities at 1650° C. in CaO–$SiO_2$–$Al_2O_3$ melts**

is much less favourable for desulphurization than that for CaO or 'FeO.' The activity of $MgO_{(s)}$ in an MgO–$SiO_2$ melt at 0·5 molar is considerably greater (about 0·1) than in the corresponding CaO–$SiO_2$ melt (about 0·006). The $C_S$ value for this MgO–$SiO_2$ mixture is therefore not so small as the value of $K_{12}$ might at first sight suggest. On the other hand if the curve for MgO–$SiO_2$ melts could be extended to higher molar fractions of magnesia (with, say, supercooled melts) it would not rise so steeply as the curve for lime, because the activity of the basic oxide can never exceed unity. It could, however, rise rather more steeply than the curve for ferrous oxide. For a similar reason the curve for lime–alumina (a pair of oxides which interact less strongly with each other than lime–silica) should rise rather less steeply than that for lime–silica.

It is interesting to observe in Fig. 5 how the $C_S$ values for the complex slags investigated by Chipman *et al.* at 1600° C. combine with the authors' $C_S$ values for CaO–$SiO_2$ melts at this same temperature to produce an **S**-shaped curve across the diagram. This is of course in line with the finding that the $C_S$ values are predominantly dependent on the basic-oxide activities. The $C_S$ values for the complex mixtures at the highest molar percentage of base approach the $C_S$ value calculated for pure 'FeO.' This is in spite of the fact that the most basic of these complex mixtures, including the basic O.H. slag studied by the authors, were sometimes high in CaO (up to 0·57 molar) and sometimes high in 'FeO.' This, again, arises presumably from the similar values obtaining for $K_{10}$ and $K_{11}$.

Figure 6 shows how the sulphur capacities vary with temperature. The slopes of the lines give the heat changes associated with the sulphide reaction in each case: $(O) + \tfrac{1}{2}S_2 = (S) + \tfrac{1}{2}O_2$.

### Sulphide Capacities of CaO–$SiO_2$–$Al_2O_3$ Slags

The sulphide capacities calculated from all the results obtained at 1650° C. for the CaO–$SiO_2$–$Al_2O_3$ system are plotted in the ternary diagram, Fig. 7. Although the number of compositions investigated does not permit accurate construction of the constant $C_S$ lines, it is adequate to show the general form of the diagram. The results at 1500° C. have also been used as a guide in drawing the contours on the

assumption that the pattern of the constant $C_S$ lines is the same at 1650° C. as at 1500° C.

The pattern of the lines is what would be expected if the activity coefficient of CaS were approximately constant and the sulphide capacities followed the CaO activities. The notable point is that the $C_S$ values tend to a maximum along the $CaO–Al_2O_3.SiO_2$ join. The interaction energy of $SiO_2$ and $Al_2O_3$ is large: $\Delta H°_{(298°K.)}$ is equal to a value of $-46 \pm 3$ k.cal. for the formation of sillimanite ($Al_2O_3.SiO_2$) from its component oxides, whereas the corresponding values for $CaO.SiO_2$, $2CaO.SiO_2$, and $3CaO.Al_2O_3$* are $-21{\cdot}25 \pm 0{\cdot}5$, $-29{\cdot}8 \pm 3$, and $-4{\cdot}0 \pm 10$ k.cal., respectively.[21] Maximum CaO activities are therefore to be expected for melts in which $SiO_2$ and $Al_2O_3$ are present in approximately equal molar proportions. In a precisely similar way, activity coefficients of ' FeO ' in ' FeO '–CaO–$SiO_2$ melts are a maximum when the $CaO/SiO_2$ ratio is about 2 : 1,[27] and ' FeO ' solubilities in ' FeO '–CaO–$P_2O_5$ melts are a minimum when the molar ratio $CaO/P_2O_5$ is about 3 : 1.[18]

## STRUCTURAL CONSIDERATIONS

The work that has been done on the structure of silicate glasses and of crystalline silicates, *e.g.*, by Bragg,[2] Biscoe *et al.*,[1] and Warren and Biscoe,[28] indicates that in any silicate melt there can be only three main types of oxygen atom: those bonded to two silicon atoms ( ⋮ Si—O—Si ⋮ ), those bonded to one silicon atom and associated with metal atoms (*e.g.*, ⋮ Si—$O^-$ $\frac{1}{2}Ca^{2+}$), and those independent of silicon and associated with metal atoms only (*e.g.*, $O^{2-}$ $Ca^{2+}$). The proportions of these three types will presumably depend upon the proportions of silica and metal oxide in the melt, and will be controlled by an equilibrium of the type

$$O^{2-} + ⋮Si—O—Si⋮ = 2\,(⋮Si—O^-) \quad \text{.....(13)}$$

for which $K_{13} = (⋮Si—O^-)^2/(O^{2-})(⋮Si—O—Si⋮)$. More complex equilibria, such as the following, are possible but the above is the simplest, and on structural grounds the most reasonable:

$$O^{2-} + Ca^{2+} + ⋮Si—O—Si⋮ = (⋮Si—O^-Ca^{2+}O^-—Si⋮) \quad \text{...(14)}$$

for which $K_{14} = (⋮Si—O^-\ Ca^{2+}O^-\ —Si⋮)/(O^{2-})(Ca^{2+})(⋮Si—O—Si⋮)$. In the highly siliceous melts, there will be very few $O^{2-}$, and in the very basic melts very few oxygens bonded to two silicons. The values of $K_{12}$ (or $K_{13}$) will clearly increase, from one metal oxide to another, as the free energy of interaction of oxide and silica becomes more negative.

The question arises whether the oxygen atoms participating in the sulphide and sulphate equilibria (1) and (2) come from one or all of these three types. The sulphur-holding capacities of all the silicate melts investigated decrease as the silica content increases and appear to follow the metal-oxide activities. In the case of $CaO–SiO_2$ mixtures at 1650° C., for example (*see* Fig. 5), the sulphur-holding capacity decreases by a factor of about 630 as the molar fraction of CaO falls from 0·90 to 0·30. It appears, therefore, that sulphur does not readily replace oxygen atoms bonded to two silicons. Between 0·3 and 0·6 molar fraction of CaO, the number of oxygen atoms bonded to one silicon atom only in a mole of melt ($n_{CaO} + n_{SiO_2} = 1$) is increased by, at most, a factor of 2. Owing to the equilibrium (13), the increase will actually be rather less. An increase in $C_S$ of about twofold would thus be expected if the most important oxygen atoms participating in the sulphide and sulphate equilibria were those bonded to one silicon only. The actual increase is about elevenfold at 1500° C. and eightfold at 1650° C. If the silicate equilibrium (13) were to hold in the melt the increase in ($O^{2-}$) could well lie in this range, depending on the value of $K_{13}$. It thus seems extremely likely that the only oxygen atoms which are readily replaceable by sulphur, or which readily form sulphate, are those not bonded to silicon at all.

It seems probable that, in the case of aluminate melts also, the important oxygen atoms are those not bonded to any aluminium. Our structural knowledge of aluminate melts is, however, nowhere near as clear as that of silicate melts, so that conclusions in this case cannot be so definite.

## DESULPHURIZATION OF METALS BY SLAGS

Figure 5 is of particular interest in connection with the desulphurization of metals by slags. Factors leading to *high sulphur capacities* and hence good desulphurizing powers for binary and more complex silicate mixtures are clearly:

(i) High CaO, ' FeO,' or MgO contents
(ii) Low CaS, MgS, FeS activity coefficients
(iii) Favourable free energies of formation of the sulphide from the oxide.

The first criterion can be obtained by making the ratios $CaO/SiO_2$, etc., large. It is evident, however, from the results obtained with ' FeO,' that it is high CaO, MgO or ' FeO ' *activities*, rather than contents, which are important. Ferrous oxide, whose activity coefficient is not markedly lowered by silica, thus, in theory, shows a considerable advantage over CaO or MgO in more siliceous slags. This advantage can unfortunately only be made use of under conditions where the ' FeO ' will be neither reduced to metal nor oxidized to the ferric state. There is nothing obvious that can be done about (ii): the sulphide activity coefficients seem to be much the same in all the binary slags studied. The order of advantage for (iii) is CaO ~ FeO > MgO.

From the form of the sulphide equilibrium constant, equation (1), it follows that factors leading to a high sulphur content in any particular slag in equilibrium with a separate metal phase are:

(i) High sulphur potential in the system
(ii) Low oxygen potential.

The efficiency of any slag as a desulphurizer is thus determined essentially by the oxygen potential, or the oxygen content, in the metal. The sulphur partition (S)/[S] is inversely proportional to $(pO_2)^{\frac{1}{2}}$ or [O] metal.

Figure 5 now summarizes all the reliable data available, directly and indirectly, on the sulphur capacities of silicate melts. There is agreement between the authors' results and those of Hatch and Chipman[9] when the former are extrapolated to extremely low oxygen pressures, and with those of Fetters and Chipman[7] and Winkler and Chipman[29] when they are extrapolated to more basic compositions than can be obtained at 1650° C. with the binary

* No figure is available for other calcium aluminates.

mixtures. It is therefore evident that equilibrium (1) controls the sulphide content of a slag in equilibrium with any sulphur-containing phase, be it gas or metal, irrespective of the prevailing oxygen potential or the slag composition. It is not necessary to invoke two separate equilibria, one important at the very low oxygen potentials of the blast-furnace and another important at the substantially higher oxygen potentials prevailing in the O.H. furnace. It is now clear that the equilibrium controlling the partition of sulphur between slag and iron or steel is:

$$[S] + (O) = [O] + (S) \quad \ldots\ldots\ldots\ldots\ldots\ldots (15)$$
$$(S)/[S] = K_{15}(O)/[O]$$

The reason for the apparent independence of (S)/[S] and [O] found by Grant and Chipman,[8] under conditions corresponding approximately to those obtained in the O.H., is clearly that the ' FeO ' content of the slag, and hence its metal-oxide activity, increases as [O] increases. The deleterious effect of the [O] on the desulphurization of the metal *via* equilibrium (15) is almost completely offset by the simultaneous advantageous increase in (O).

It is interesting to note that the sulphur capacities of iron blast-furnace slags (at 1500° C.) are lower than those of basic O.H. slags (at 1650° C.) by a factor of about 100. The blast-furnace has, nevertheless, a marked advantage over the O.H. for desulphurization, as the controlling oxygen potential in the slag and metal is much lower For the C–CO (1 atm.) equilibrium, approached in the blast-furnace, $pO_2$ is about $10^{-16}$ atm., whereas, for the 0·06% [O] in the Fe–[C]–[O] equilibrium, approached in the O.H., $pO_2$ is about $10^{-9}$ atm. The higher temperature of the O.H. causes a raising of the chemical potential of sulphur in iron and favours desulphurization of the metal by a factor of about two. The presence of carbon and silicon in the blast-furnace metal also favours desulphurization, as it raises the chemical potential of the dissolved sulphur by a factor of about three. If equilibrium conditions were attained in both cases the sulphur partition obtained in the blast-furnace would be some 30 times better than in the O.H. In practice it is about eight times as good, presumably because of the lack of equilibrium with respect to oxygen or sulphur in the blast-furnace.

## TRANSFER OF SULPHUR BETWEEN SLAG AND GAS IN THE OPEN HEARTH

A theoretical study of the factors controlling the transfer of sulphur between slag and gas in the O.H. furnace was made by Richardson and Withers[22] in 1950 on the basis of the then existing knowledge of the behaviour of sulphur and oxygen in molten iron and the assumption that the equilibrium partitions of sulphur between slag and metal, and slag and gas, could be represented by the equations:

$$(S) + [O] = (O) + [S] \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$
$$(S) + \tfrac{1}{2}O_2 = (O) + \tfrac{1}{2}S_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots (17)$$

It was then predicted that under the range of oxygen pressures of interest in steel making, sulphate should be of no importance in the slag and the oxygen potentials for minimum sulphur should be those at $CO/CO_2$ ratios of 1 : 35 at 1527° C. and 1 : 25 at 1627° C. These assumptions can now be seen to be correct, the predicted conditions for minimum sulphur in the slag not being far different from those observed in the present authors' experiments: $pO_2 = 10^{-5}$, $CO/CO_2 = 1 : 20$ at 1500° C.; $pO_2 = 10^{-3\cdot7}$, $CO/CO_2 = 1 : 20$ at 1650° C. The conclusions in the earlier paper can therefore be taken as substantially correct. On the basis of the new data reported in this paper it is, however, possible to consider the slag–gas equilibrium more directly than hitherto, without the complicating necessity of expressing the sulphur-holding power of the slag in terms of the sulphur and oxygen contents of a hypothetical equilibrium metal.

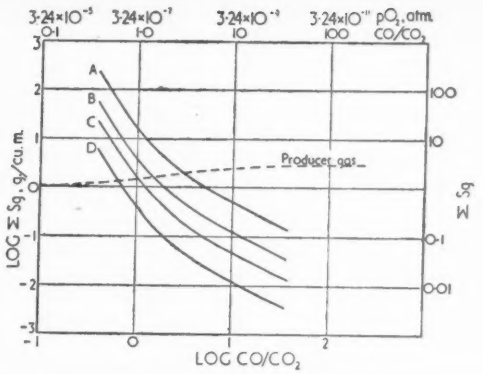



**Fig. 8—Relationships between degree of combustion and sulphur content of a typical producer gas in equilibrium with basic slags at 1627° C. The curves change very little with temperature**

Figure 8 (which corresponds closely with Fig. 2 of Richardson and Withers[22]*) shows the conditions for equilibrium between the sulphur in two typical basic slags and a typical producer gas as it is burnt. The composition assumed for the producer gas was:

| $CO_2$, % | CO, % | $H_2$, % | $H_2O$, % | $N_2$, % | $CH_4$, % |
|---|---|---|---|---|---|
| 8 | 22 | 16 | 1 | 50 | 3 |

The sulphur capacities of the slags were taken as 0·030% (*i.e.*, about the same as that which the basic slag described in Table III would have at 1627° C.) and 0·060%, which would represent the extreme of basic practice (*see* footnote, p. 8). The sulphur contents were taken as 0·4, 0·04, 0·2, and 0·02% as representative of conditions both before the slag has taken much sulphur from the metal, and at the end of the refining process. Slags *A* and *C* would be in equilibrium with metal containing 0·06% [O] and 0·1 and 0·01% [S], respectively. Slags *B* and *D* would correspondingly be in equilibrium with metals containing 0·06% [O] and 0·025 and 0·0025% [S].

The broken line represents the sulphur contents in grammes per cubic metre ($\Sigma S_g$) at S.T.P. of a producer gas as already described but containing initially 3 g./cu.m. of sulphur, as it is burnt and diluted with nitrogen. The points in which this line intersects the

* The two sets of curves do not agree completely; those in the earlier paper should in theory be corrected to take account of the presence of SO and HS in the hot gases, and also the newer results of Sherman, Elvander, and Chipman[25] on the thermodynamics of sulphur in molten iron. The two corrections do, however, almost compensate one another.

set of curves *A* to *D* show the degrees of combustion which must obtain in the producer gas, which comes into contact with the slag, if it is not to pass sulphur to the bath and thereby hinder the desulphurization of the metal. It can be seen that even for the slag *D*, which corresponds to an extremely basic one before it has started to desulphurize the metal, there is no danger of pick-up of sulphur from this producer gas provided that $CO/CO_2$ is $< 0{\cdot}63$, *i.e.*, the gas striking the slag is 61% burnt. With more sulphur in the slag or with a less basic slag, the half-burnt condition would be safe. There is little danger of pushing sulphur into the slag as sulphate under the fully burnt condition. If the gases were burned with 10% excess air, $pO_2$ at the fully burnt condition would be 0·015 atm. From the sulphate equilibrium data given in Table III and in Fig. 3, it can be estimated* that the minimum values of $\Sigma S_g$ in equilibrium with these slags would be about 7 for *D*, 28 for *C*, 70 for *B*, and 280 for *A*. (These should be minimum values, as no allowance has been made for the greater proportion of lime and iron oxide associated as ferrites at 0·015 atm. $pO_2$, than at the 0·01 atm. for which the sulphate point on the B.O.H. line in Fig. 3 applies.)

The curves shown in Fig. 8 are shifted very little by temperature relative to the $\Sigma S_g$ and $CO/CO_2$ scales (not the $pO_2$ scale). This is different from the case described in Fig. 1 of Richardson and Withers,[22] where the curves were drawn for fixed sulphur and oxygen contents of the hypothetical equilibrium metal, and not for fixed sulphur contents of the slags.

Koch and Fink[15] using radio-sulphur in the heating gases of a basic O.H. furnace have shown that there is fairly rapid exchange of sulphur between slag and gas. The question therefore arises why substantial losses of sulphur do not occur from slag to gas in the O.H. There appear to be two possible reasons. Much of the gas striking the slag surface in the centre of the bath may be so little burnt that it transfers as much sulphur to the slag as is lost from the slag under the more oxidizing conditions obtaining around the periphery of the bath. Alternatively, drops of metal projected through the slag and into the gases during the boil may pick up as much sulphur from the gas as is lost from the slag. It would be interesting to determine from works' experiments how much metal is thus projected. If the quantities are not great there is a strong case for improving port or burner design to give more complete combustion of the furnace fuels before they can strike the slag surface.

The general conclusions reached here should apply to oil-fired as well as to gas-fired furnaces. The safe combustion limits for the gas–slag reactions may be slightly, but are probably not markedly, different from those shown in Fig. 8. There is, however, the additional complication that sulphur may be carried into the slag by oil drops falling into it. Whether this is important or not is unfortunately unknown.

* Since there is a difference of 23° between the temperatures for which Figs. 3 and 8 apply, a value must be assumed in this calculation for the temperature coefficient of the sulphate equilibrium in the basic O.H. slag. Only an approximate value is required as the temperature interval is small; it was taken to be the same as for slag S1 in Fig. 2.

## BLOWING OF BLAST-FURNACE SLAG

The authors' results are applicable to two processes which might under certain conditions find useful applications. One is the desulphurization of blast-furnace slag and its re-use when hot to desulphurize blast-furnace metal. The other is the direct conversion of sulphur in blast-furnace slag to elemental sulphur.

It is obvious from the results shown in Fig. 1 that sulphur can be removed from a blast-furnace slag by blowing it with air. The typical practice blast-furnace slag described in Table III had a sulphur capacity at 1500° C. of $3{\cdot}9 \times 10^{-4}$, which is about three times greater than the value for slag S1. It follows[19] that its sulphate capacity will also be about three times greater than that for S1, so that at an oxygen pressure of 0·2 (equivalent to air) the equilibrium gas could carry 1% $SO_2$ with the slag sulphur as low as 0·01%. In practice, however, the oxygen in the air blown through the slag will be used up on its way through, so that the oxygen pressure in the emergent gas will be much less than 0·2 atm. As Fig. 1 shows, the process of desulphurization should be correspondingly more efficient. The desulphurization of part of the molten blast-furnace slag by blowing with air, and its immediate re-use as a desulphurizer of blast-furnace metal, are therefore worth considering when it is remembered that (S)/[S] for basic blast-furnace conditions is about 20.

If the chemistry of blowing air through a blast-furnace slag is considered in greater detail, it becomes evident that there is a possibility of converting the sulphur in the slag directly to elemental sulphur by a blowing operation followed by condensation of the sulphur-bearing gases. This possibility can be assessed from Fig. 1*a* and the available thermodynamic data on $SO_2$, $S_2$, S, COS, $CS_2$, CO, and $CO_2$. The typical blast-furnace slag described in Table III had sulphide and sulphate capacities about three times as great as slag S1 in Fig. 1*a*. The effect of blowing ordinary air and air containing $CO_2$ through this slag will be considered. The partial pressures (in atmospheres) of the sulphur-containing gases $S_2$, S, SO, $SO_2$ in equilibrium with blast-furnace slags of sulphur capacity $4 \times 10^{-4}$ and sulphur contents of 2·0 and 0·2% at various low oxygen pressures are shown in Table IV. These two sulphur contents approximate to a fresh slag and one from which 90% of the sulphur has been removed. If air is blown through the slag the reactions leading to the removal of sulphur may be represented as follows:

$$\tfrac{1}{2}O_2 + (S) = \tfrac{1}{2}S_2 + (O) \quad \text{.....(18)}$$
$$\tfrac{1}{2}O_2 + (S) = S + (O) \quad \text{.....(19)}$$
$$\tfrac{3}{2}O_2 + (S) = SO_2 + (O) \quad \text{.....(20)}$$
$$O_2 + (S) = SO + (O) \quad \text{.....(21)}$$

If elemental sulphur is to be obtained the process must be designed so that all the oxygen in the air is used up in its passage through the slag and there is thus no substantial oxygen pressure in the emergent gases. Otherwise the sulphur will be present in these gases entirely as $SO_2$.

It follows from equations (18) to (21) that if all the oxygen in the air blown is to be used up:

$$2pS_2 + 3pSO_2 + pS + 2pSO = 2 \times 0{\cdot}2 \text{ atm.}$$

Therefore with a slag containing 2% S, $pO_2$ will be about $10^{-8\cdot3}$ (obtained by graphical interpolation between $10^{-8}$ and $10^{-8\cdot5}$ in Table IV) and the loss of sulphur as $SO_2$ may be about 12%. With a 0·2% slag, $pO_2$ will be about $10^{-7\cdot1}$ (interpolation between $10^{-7}$ and $10^{-7\cdot5}$) and the loss of sulphur as $SO_2$ may then be as high as 60%. If a reasonable yield of elemental sulphur is to be obtained, the gases must emerge from the slag somewhere near equilibrium with 2% of sulphur. A counter-current process with slag and gas flowing in opposite directions is therefore essential. With such a process the pressure of sulphur-containing gases in the emergent gases should build up to about 0·2 atm. An increase of temperature would be expected to decrease the proportions of $SO_2$ and SO in the emergent gases, but not to have any other significant effect.

The displacement of sulphur from the slag *via* reaction (18) is strongly exothermic; $\Delta H_{1500^\circ C.}$ should be about — 56,000 cal., which is the value derived by the authors from the temperature coefficient of $C_S$ for slag S6, which was similar in composition to blast-furnace slag (*see* Fig. 6). From this value of $\Delta H$ it can be calculated that the heat evolved in making the monatomic sulphur by reaction (19) will be about — 17 k.cal. and the heats for reactions (20) and (21) correspondingly — 143 and — 81 k.cal. The total heat evolved in using up 1 mole of oxygen will thus be about — 112 k.cal. The heat required to raise 1 mole of oxygen from 298° to 1750° K. (approximately the temperature of the slag) is 12 k.cal. and to raise 4 moles of nitrogen to this same temperature is 45 k.cal., *i.e.*, 57 k.cal. together. The blowing of slag with cold air is thus an exothermic process and a hot blast might not therefore be necessary. The remaining 65 k.cal. would be used in heating the slag. This would be made available in approx. 3200 g. of slag (32 × 100) holding 2% sulphur originally. It could thus raise its temperature by about 75° C., and so make up for some of the inevitable heat lost due to the mechanics of the process.

The loss of 15% of the sulphur as $SO_2$ could be prevented by blowing with a mixture of oxygen and $CO_2$ or air and $CO_2$. The most important reactions in which the $CO_2$ can take part are:

$$3CO_2 + (S) = 3CO + SO_2 + (O) \text{ at } 1500^\circ C. \quad \ldots\ldots(22)$$

$$2CO_2 + (S) = 2CO + SO + (O) \text{ at } 1500^\circ C. \quad \ldots(23)$$

$$CO_2 + (S) = CO + \tfrac{1}{2}S_2 + (O) \text{ at } 1500^\circ C. \quad \ldots\ldots(24)$$

$$SO_2 + 2CO = 2CO_2 + \tfrac{1}{2}S_2 \text{ on cooling} \ldots\ldots\ldots (25)$$
$$K_{600^\circ C.} = 9\cdot3 \times 10^6$$

$$2SO = SO_2 + \tfrac{1}{2}S_2 \text{ on cooling} \ldots\ldots\ldots\ldots(26)$$
$$K_{600^\circ C.} = 10^5$$

$$CO + \tfrac{1}{2}S_2 = COS \text{ on cooling} \ldots\ldots\ldots\ldots(27)$$
$$K_{600^\circ C.} = 1\cdot5 \times 10^3$$

If loss of sulphur as COS, reaction (27), is to be avoided, the CO produced in the blowing operation should be just sufficient to reduce the $SO_2$ in the blown gas, by reaction (25), as the gases cool. This could be arranged with a mixture of 30% burnt gas (33% $CO_2$, 67% $N_2$) and 70% air. The pressure of the sulphur-containing gases could then build up to about 17% in the emergent gases, which is not much less than with air, and the loss of sulphur as $SO_2$ be substantially reduced or completely avoided. The use of such a gas mixture would, as in the case of air, require a counter-flow process. The proportion of $N_2$, $CO_2$, and $O_2$ required in the ingoing gas mixture would be dependent on the slag with which the emergent gases approach equilibrium. If this sulphur content were to change, as with a batch process, the composition of the ingoing gases would have to be continually adjusted.

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## Table IV

**PARTIAL PRESSURES OF SULPHUR-BEARING GASES IN EQUILIBRIUM WITH BLAST-FURNACE SLAGS OF SULPHUR CAPACITY $4 \times 10^{-4}$ wt.-%**

| Partial Pressures, atm. | | | | | Σp* | ΣO† | % S Left as $SO_2$ in Cooled Gases‡ | CO/(CO+$CO_2$) |
|---|---|---|---|---|---|---|---|---|
| $pO_2$ | $pS_2$ | $pSO$ | $pSO_2$ | $pS$ | | | | |
| 2% S in slag | | | | | | | | |
| $10^{-5}$ | 15·6 | 25·0 | 308 | 0·12 | — | — | 86 | — |
| $10^{-6}$ | 25·0 | 10·0 | 38·9 | 0·15 | — | — | 44·2 | — |
| $10^{-7}$ | 2·5 | 1·0 | 1·23 | 0·047 | 4·78 | 10·74 | 24·1 | 33·2 |
| $10^{-7\cdot5}$ | 0·79 | 0·32 | 0·22 | 0·027 | 1·36 | 2·91 | 17·7 | 46·9 |
| $10^{-8}$ | 0·25 | 0·100 | 0·039 | 0·015 | 0·404 | 0·83 | 13·6 | 61·1 |
| $10^{-8\cdot5}$ | 0·079 | 0·032 | 0·0069 | 0·008 | 0·126 | 0·25 | 11 | 73·7 |
| $10^{-9}$ | 0·025 | 0·0100 | 0·0012 | 0·0047 | 0·041 | 0·08 | 11 | 83·2 |
| 0·2% S in slag | | | | | | | | |
| $10^{-5}$ | 0·156 | 2·50 | 30·8 | 0·01 | 33·5 | — | 95 | — |
| $10^{-6}$ | 0·25 | 1·00 | 3·89 | 0·015 | 5·15 | 14·2 | 81 | — |
| $10^{-7}$ | 0·025 | 0·100 | 0·123 | 0·0047 | 0·253 | 0·62 | 62 | 33·2 |
| $10^{-7\cdot5}$ | 0·0079 | 0·032 | 0·022 | 0·0027 | 0·065 | 0·15 | 52 | 46·9 |
| $10^{-8}$ | 0·0025 | 0·010 | 0·0039 | 0·0015 | 0·0179 | 0·04 | 44 | 61·1 |
| $10^{-9}$ | 0·00025 | 0·0010 | 0·00012 | 0·00047 | 0·00184 | 0·003 | 34 | 83·2 |

* $\Sigma p = pO_2 + pS_2 + pS + pSO + pSO_2$ † ΣO = Oxygen requirement = $2pS_2 + 3pSO_2 + pS + 2pSO$
‡ Calculated from ($pSO_2 + \frac{1}{2}pSO$) as the SO should decompose to $SO_2$ and $S_2$ on cooling

author (C.J.B.F.), a member of the staff of the Association, to work in the Nuffield Research Group. They are much indebted to Dr. J. Pearson for his interest and criticism and to Mr. M. W. Davies for the measurements quoted in Table III.

## APPENDIX

### Thermodynamic Data Used

**Calcium**

$$CaO_{(s)} + \tfrac{1}{2}S_2 = CaS_{(s)} + \tfrac{1}{2}O_2$$

$$\Delta G^\circ_{1023\text{–}2000^\circ\,K.} = +23{,}020 - 1{\cdot}25T \pm 500 \text{ cal.}$$

$$\Delta H^\circ_{1700\text{–}2000^\circ\,K.} = +24{,}000 \pm 1500 \text{ cal.}$$

Rosenqvist[23] has studied the equilibrium $CaO + H_2S = CaS + H_2O$ between 1023° and 1698° K.; his results were combined with the free-energy data for $H_2O$ and $H_2S$ (Rossini *et al.*,[24] Richardson and Jeffes[20]).

$$CaSO_{4(s)} = CaO_{(s)} + \tfrac{1}{2}S_2 + \tfrac{3}{2}O_2$$

$$\Delta G^\circ_{1773^\circ\,K.} = 65{,}000 \pm 2000 \text{ cal.}$$

$$\Delta G^\circ_{1923^\circ\,K.} = 54{,}000 \pm 3000 \text{ cal.}$$

$$\Delta H^\circ_{1700\text{–}2000^\circ\,K.} = +195{,}000 \pm 5000 \text{ cal.}$$

Zawadski's equilibrium data[30] for the reaction $CaSO_4 = CaO + SO_2 + \tfrac{1}{2}O_2$ over the range 1180–1373° C. were extrapolated linearly to the required temperatures, and the resulting free energies were combined with those for the reaction $SO_2 = O_2 + \tfrac{1}{2}S_2$ (Richardson and Jeffes[20]).

**Magnesium**

$$MgO_{(s)} + \tfrac{1}{2}S_2 = MgS_{(s)} + \tfrac{1}{2}O_2$$

$$\Delta G^\circ_{1380\text{–}2000^\circ\,K.} = +44{,}180 - 2{\cdot}85T \pm 8000 \text{ cal.}$$

A free-energy equation, which can be derived for the formation of MgO from its heat of formation (Shomate and Huffman[26]) and the appropriate heat-capacity,[13] entropy,[14] and latent-heat data,[11,12] was combined with that derived by Richardson and Jeffes[20] for the reaction $Mg + \tfrac{1}{2}S_2 = MgS$.

**Iron**

$$\text{'FeO'}_{(liq.)} + \tfrac{1}{2}S_2 = \text{'FeS'}_{(liq.)} + \tfrac{1}{2}O_2$$

$$\Delta G^\circ_{1642\text{–}2000^\circ\,K.} = +25{,}280 - 2{\cdot}41T \pm 3000 \text{ cal.}$$

$$\Delta H^\circ_{1642\text{–}1800^\circ\,K.} = +27{,}600 \pm 4000 \text{ cal.}$$

Calculations on the ferrous-oxide–ferrous-sulphide equilibrium are complicated by the non-stoichiometry of 'FeO'[5] and the fact that the thermodynamics of the non-stoichiometry of 'FeS' have not been established. Approximate values for the free energy change associated with the reaction $Fe_xO_{(liq.)} + \tfrac{1}{2}S_2 = Fe_xS_{(liq.)} + \tfrac{1}{2}O_2$ can be calculated for 1670° and 1796° C. (where $x$ ranges from about 0·995 to 1·000) from the results of Grant and Chipman[8] on the sulphur equilibria between liquid iron and slags containing about 90% 'FeO,' 4% $Fe_2O_3$, and 6% MgO, and the equations of Dastur and Chipman[6] for the free energy of formation of $Fe_xO$ from iron and oxygen. The activity coefficient of $Fe_xS$ in these melts was taken as 1·5, the value calculated by Chipman[3] from the 'FeO'–'FeS' phase diagram and the heats of fusion of 'FeO' and 'FeS.' The values of $pS_2$ in equilibrium with liquid iron containing the appropriate amounts of sulphur were taken from the work of Sherman, Elvander, and Chipman.[25]

Approximate values for this same $\Delta G^\circ$ may also be calculated, by neglecting the non-stoichiometry and combining the free-energy equations[6] for

$$xFe + \tfrac{1}{2}O_2 = Fe_xO$$

$$\Delta G^\circ_{1808\text{–}2000^\circ\,K.} + -56{,}830 + 11{\cdot}94T.$$

with that derived as described below, for

$$Fe + \tfrac{1}{2}S_2 = FeS$$

$$i.e., \quad \Delta G^\circ_{1800\text{–}2000^\circ\,K.} = -32{,}050 + 9{\cdot}53T.$$

The FeS equation of Richardson and Jeffes[20] was extrapolated beyond the melting points of FeS and Fe by introducing the appropriate heats and entropies of fusion (Coughlin,[4] Kelley[14]) but neglecting changes in heat capacity. The $\Delta G$ values obtained in this way are slightly more negative than those derived from Grant and Chipman's results: 100 cal. at 1670° and 1900 cal. at 1796° C. Better agreement could not have been expected in any case. It appears that the errors arising from the neglect of non-stoichiometry are small. The approximate equation proposed above for $\Delta G^\circ$ for the reaction $\text{'FeO'}_{(liq.)} + \tfrac{1}{2}S_2 = \text{'FeS'}_{(liq.)} + \tfrac{1}{2}O_2$ is based on the mean of both calculations.

The corresponding value for $\Delta H^\circ_{1500\text{–}1800\,^\circ K.}$ was obtained from the difference between

$$\Delta H^\circ_{1680^\circ\,K.} = -55{,}450$$

$$\text{for } 0{\cdot}95\,Fe_{(\gamma)} + \tfrac{1}{2}O_2 = Fe_{0{\cdot}95}O_{(liq.)}$$

$$\Delta H^\circ_{1500^\circ\,K.} = -27{,}900 \text{ for } Fe_{(\gamma)} + \tfrac{1}{2}S_2 = FeS_{(liq.)}$$

The justification for again neglecting the non-stoichiometry is that Darken and Gurry[5] have shown that for 'FeO'$_{(liq.)}$ the value of $\Delta H^\circ$ per gramme-atom of oxygen changes little with composition; presumably the $\Delta H^\circ$ values for the sulphide behave similarly, so that $\Delta H^\circ$ for the 'FeO'–'FeS' conversion would be even less dependent on composition. The 'FeO' value was taken from Humphrey, King, and Kelley.[10] The 'FeS' value was calculated from (*a*) Zeumer and Roth's[31] value of −22,800 cal. for $\Delta H^\circ_{298^\circ K.}$ from iron and rhombic sulphur; (*b*) $\Delta H^\circ_{298^\circ K.}$ for $S_{(rh)} = \tfrac{1}{2}S_{2(g)}$[20]; (*c*) the heat capacity and heat of fusion of $FeS_{1{\cdot}02}$ from Coughlin,[4] and (*d*) the heat contents of Fe and $S_2$ from Kelley.[13] The probably small differences between the heat capacities and heats of fusion of FeS and $FeS_{1{\cdot}02}$ were neglected.

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# Some Effects of Hydrogen on the Delayed Fracture of High-Tensile Steel

*By Winifred A. Bell, B.A., and A. H. Sully, M.Sc., Ph.D., F.Inst.P., F.I.M.*

SYNOPSIS

An investigation has been made of the 'delayed' fracture (*i.e.*, fracture under the prolonged application of stress at room temperature) of 0·9% carbon steel in the form of circlips into which hydrogen was introduced by electrolytic pickling. Even after storage and tempering treatments, which produce a more or less complete recovery of the normal mechanical properties, the tendency to fracture with short delay times is greater for samples that have been pickled. The effect of hydrogen on the delayed-fracture characteristics increased with the hardness of the steel. The results are discussed on the basis of the Griffith crack theory of brittle fracture.

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THIS investigation was undertaken in an attempt to explain the delayed fracture of certain high-tensile steel bolts. These bolts were made of steel to specification DTD4*a* and were cathodically pickled in the fully heat-treated condition before cadmium plating. Fracture had occurred in a very small proportion of these bolts after they were tightened to an initial stress of about 80 tons/sq. in. Fracture was in no case immediate but usually occurred within a few minutes of tightening. An examination of the fractured bolts revealed no obvious reason for the failures. No flaws were detected at the fracture surface, and tensile specimens machined from the fractured bolts gave normal values for strength, elongation, and reduction in area. However, since similar failures had never been encountered in studs which had not been pickled or cadmium-plated it was reasonable to suppose that the failures were in some way associated with hydrogen introduced into the steel during these processes. The embrittlement of steel by hydrogen is, of course, a well known phenomenon but, as normally encountered, it is usually associated with reduced values of elongation and reduction in area ; this, however, was not true in the present instance. The delayed fracture of steel when subjected at room temperature to stress below that required to cause immediate failure is also known but has not been studied extensively. Bucknall, Nicholls, and Toft[1] have shown that high-tensile steels with hardnesses over 400 D.P.N. are susceptible to this type of failure, although in their work they found that such failures usually occurred a considerable time after the original application of stress. The present investigation has shown that small quantities of hydrogen in the steel may markedly reduce the time required for the development of such delayed fractures.

## EXPERIMENTAL TECHNIQUE

A simple technique has been evolved which makes it relatively easy to test fairly large numbers of specimens. Specimens in the form of 'Seeger' circlips of plain 0·8–0·9% carbon steel are used.

The experimental arrangement is illustrated by Fig. 1, which shows an unstressed and a stressed specimen. One end of the clip is pinned and held stationary in a jig and the other end is pinned to a bolt so that it can be moved away from the fixed end. The distance between the two ends can be read from a vernier scale attached to the jig which is mounted during setting in a holder carrying a corresponding scale. Thus, the stress applied to the clip can be expressed as the displacement between the two ends

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of the clip. When the deflection for fracture was to be measured the clips were strained as nearly as possible at a constant rate.

In the as-received condition the circlips show a considerable scatter in the deflection required to cause fracture. This scatter was reduced considerably by a stress-relieving treatment of 24 hr. at 160° C., which was adopted as a standard procedure.

Hydrogen was introduced into the clips by a standard pickling treatment in which they were treated cathodically in $2 \cdot 5N$ $H_2SO_4$ for $\frac{1}{2}$ hr. at a current of 2 amp. per clip.

During the course of the investigation large numbers of circlips were tested. In the as-received condition these showed a wide scatter in hardness. The work disclosed a considerable dependence of the delayed-fracture characteristics on the hardness of the steel. For this reason the results on the delayed-fracture habit have been divided into two groups, one relating to 'soft' clips of average hardness about 500 D.P.N., the measured hardness range being 481–517 D.P.N., and one relating to 'hard' clips of average hardness about 560 D.P.N., the measured range being 537–590 D.P.N. In view of the simple experimental technique it was possible to carry out most of the work in which the effect of recovery heat-treatment was studied on a semi-statistical scale on batches of 100–200 clips, in both ranges of hardness.

## RESULTS

The average deflection required to break the clips in the initial stress-relieved condition was 1·110 in. Immediately after electrolytic pickling this was considerably reduced to a mean value of about 0·300 in. The effect of storage at room temperature was to produce a gradual recovery of strength caused by the diffusion of hydrogen out of the specimen. Recovery was substantially complete after 115 hr. at room temperature and after this period the mean breaking deflection was 1·034 in., the recovery being to 93% of the original breaking deflection.

The delayed fracture of a batch of 'hard' clips was first studied in the unpickled condition, the clips being set to deflections corresponding to fixed amounts smaller than that required to cause immediate fracture. Except at the lowest values of applied stress, a proportion of the clips always broke during setting to the test deflection because of the fairly wide scatter of breaking deflection. The remainder were left set at this deflection until fracture occurred or until the test was discontinued, usually after 250–350 hr.

As expected by analogy with the earlier investigation of Bucknall, Nicholls, and Toft,[1] there was a high incidence of delayed fracture: 80% of the total number of clips tested fractured within the duration of the test. Of these, however, only a very small proportion, 7·7% of the total (*see* Table I), broke in a test period of less than 10 min. The average time of delay was 2580 min. All the clips broke which were set at deflections of $\leqslant 0 \cdot 1$ in. less than the average breaking deflection, whereas, of those set to 0·2 in. less, about half broke and half remained unbroken after 15,000 min.

Pickled clips of corresponding hardness electrolytically pickled and allowed to recover by standing for 115 hr. at room temperature behaved quite differently in delayed-fracture tests. The proportion of clips fracturing was much the same as for the unpickled clips (all those set at 0·12 in. less than the average breaking deflection and 50% of those set at 0·23 in. less). The proportion of the clips which failed in $< 10$ min. was, however, very much higher—71% compared with 7·7% for unpickled clips. Another batch of 'hard' clips was tempered for 2 hr. at 250° C. but not pickled. The incidence of delayed fractures in $< 10$ min. was only 2·3%.

Corresponding tests on clips in the lower range of hardness showed that the tendency to fracture with a time delay is considerably influenced by the hardness of the steel. No clips tempered for 2 hr. at 250° C. without pickling failed with delay periods $< 10$ min. Pickled 'soft' clips allowed to recover for 115 hr. at room temp. showed only a 1% incidence of short-term delays, compared with 71% for 'hard' clips.

To determine whether the greatly increased tendency to fracture with short delay periods, induced by pickling, could be eliminated by a heat-treatment at a temperature which did not cause softening of the steel, experiments were made on batches of clips which were pickled, stored at room temperature for 115 hr., and then annealed for 2 hr. at 200° C. ('soft' clips), 16 hr. at 200° C. ('hard' clips), or 2 hr. at 250° C. (both). The results are given in Table I.

For 'hard' clips the incidence of short-term delayed fracture was reduced to 25% and 22% for heat-treatment at 200° and 250° C., respectively, but both values were much higher than the value of 2·3% recorded for clips tempered at 250° C. without pickling. For 'soft' clips the much smaller incidence of short-term delays was not eliminated by the tempering treatment but remained at 1–2%.

A noteworthy feature of all the results was that fracture nearly always occurred either in a short time (less than 2 min.) or in a very much longer period (several hours—usually greater than 24 hr.). Very few fractures occurred with time delays between these limits. The distinction between short-term and long-term delays based upon a time limit of 10 min. is therefore not as arbitrary a distinction as it might appear to be at first sight.

## DISCUSSION OF RESULTS

The results described in the previous section demonstrate quite clearly that the introduction of hydrogen

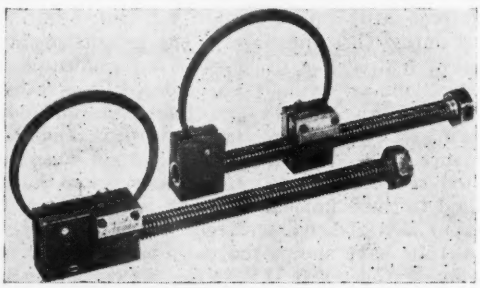

**Fig. 1—Jigs for application of controlled deflection to specimens in the form of circlips: (*left*) unstressed clip, (*right*) stressed clip**

into steel of a high hardness level exercises a marked effect on the tendency of the steel to delayed fracture at stresses below the ultimate tensile stress, even after the steel is stored or annealed to remove the absorbed hydrogen and after recovery of the mechanical properties as normally measured is substantially complete.

The whole problem of the delayed fracture of steel at atmospheric temperatures has received little attention, but it seems possible that all the observed effects may be explained by an extension of the Griffith crack theory of brittle fracture. Griffith[2] has postulated that brittle materials such as glass contain cracks. If these are greater than a certain critical size they are propagated when a stress is applied and lead to brittle cleavage failure. A critical size results from the fact that the energy associated with the spread of a crack represents the summation of two terms of opposite sign :

(i) The increase in free energy due to the formation of a new interface

(ii) The decrease in strain energy due to the formation of the crack.

When these two terms become equal the crack is propagated, but below the critical size term (i) is greater than term (ii) and the crack does not spread. There is, however, a time effect in brittle fracture. A stress which will not cause failure if applied for a short period of time will cause brittle fracture if applied for a longer period. This effect has been noted for glass by Preston[3] and by Holland and Turner.[4] To account for such delayed fracture Joffé[5] has postulated that a crack smaller than the critical size required to cause immediate failure on the application of stress can grow at a finite rate proportional to :

$$\exp\left[-\left(Q-\frac{f^2\sigma^2}{2E}\right)\Big/\,KT\right]$$

where $f$ is the stress concentration factor at the base of the notch, $\sigma$ is the applied stress, $Q$ is the energy of binding, $E$ is the elastic modulus, and $T$ is the absolute temperature. Hollomon[6] has pointed out that stress concentrations additional to those taken into account by Joffé can arise by thermal fluctuations in small volumes. The rate of crack growth in a small volume of material $v$ for a stress fluctuation $\sigma^x$ greater than the applied stress $\sigma$ is

$$R=A\times\exp\left[\frac{-(\sigma^x-\sigma)^2}{2E\times K\times T\times v}\right]\times \exp\left\{-\left[Q-\frac{f\sigma+f^x(\sigma^x-\sigma)^2}{2E}\right]\Big/\,KT\right\}$$

## Table I

### RESULTS OF DELAYED-FRACTURE TESTS IN VARIOUS INITIAL CONDITIONS

**All clips set to 0·2 in. < the mean breaking deflection**

| Initial Condition* | Percentage of Failure in <10 min. after Loading | |
|---|---|---|
| | 'Soft' Clips | 'Hard' Clips |
| Not pickled | ... | 7·7 |
| 2 hr. at 250° C., not pickled | nil | 2·3 |
| Pickled + 115 hr. at room temp. | 1 | 71 |
| ,, +2 hr. at 200° C. | 1 | ... |
| ,, +16hr. at 200° C. | ... | 25 |
| ,, +2 hr. at 250° C. | 1·5 | 22 |

*All clips received a stress-relieving heat-treatment of 24 hr. at 160° C. before subsequent treatment.

where $f^x$ is the stress-concentration factor for the excess of $\sigma^x$ over $\sigma$. Thus, under an applied stress, the slow growth of a crack nucleus due to stress concentration at the edge of the crack and to local fluctuations of stress caused by thermal agitation will occur by unit processes until finally the critical size is reached and sudden cleavage failure occurs.

In a metal having a low yield/cleavage-strength ratio brittle fracture cannot occur, even if crack nuclei are present, because plastic deformation at the edges of the crack will result in the relief of stress intensification around the crack. The work of Bucknall, Nicholls, and Toft,[2] however, shows that delayed fracture can occur in hardened steels of relatively low ductility, and it is possible that these considerations apply in such materials. The nature of the crack nucleus cannot be identified with any certainty. It may be a particle of inclusion, a discontinuity at the junction of structural constituents, or even a dislocation array.

It is now relevant to consider the effects on the fracture processes of hydrogen present in the steel. When steel is impregnated with hydrogen it is present in two forms :

(i) As atomic hydrogen present interstitially in the lattice

(ii) As molecular hydrogen formed by combination of atomic hydrogen at crack nuclei.

Since the hydrogen molecule is much bigger than the hydrogen ion, the diffusion speed of molecular hydrogen through the metal lattice is far smaller than that of atomic hydrogen. The collection of molecular hydrogen at 'rifts' in the lattice has already been postulated by Zapffe.[7] The heat of reaction $2H \rightleftharpoons H_2$ is 103 k.cal./mole. As a consequence of this large energy release the approach and combination of atomic hydrogen to form molecular hydrogen at discontinuities in the lattice leads to a highly stable concentration. Atomic hydrogen diffusing down a concentration gradient in the lattice combines to form molecular hydrogen at a sufficiently large lattice defect ; the process will continue until a high effective pressure is built up inside the discontinuity, and the work done against intramolecular forces in squeezing another molecule into the discontinuity becomes equal to the energy liberated by combination to form the molecule from the interstitial hydrogen atoms.

It is reasonable to suppose that in a steel containing hydrogen in both atomic and molecular forms the growth of crack nuclei under stress may be affected in three ways :

(i) Hydrogen present in the atomic form interstitially in the lattice may affect the cohesive interactions and may consequently alter the yield/cleavage-strength ratio. If the cohesive interaction is reduced the energy increase associated with the formation of a new interface during the growth of a crack nucleus under stress (and consequently the critical crack size) is also reduced

(ii) Hydrogen present in the molecular form in crack nuclei will set up an effective pressure in the crack which will multiply the stress concentration factors $f^x$ and $f$ in Hollomon's modification of Joffé's equation

(iii) As recently postulated by Petch and Stables,[8] absorption of hydrogen on the faces of the crack may reduce the energy required to form a new interface.

In a steel containing both atomic hydrogen in the lattice and molecular hydrogen in crack nuclei, therefore, conditions are very favourable for crack propagation and brittle fracture. Even under such conditions, however, a finite time is required for the growth of a crack under an externally applied stress to the critical value which will give cleavage failure. In work carried out by the authors on embrittled high-tensile steel bolts, impact tests on unnotched specimens did not differentiate between embrittled and non-embrittled bolts, whereas a satisfactory differentiation was made in bend tests, in which the strain rate was very much lower than in an impact test. Similarly, Seabrook, Grant, and Carney[9] in carrying out tensile tests on hydrogen-embrittled S.A.E. 1020 steel found that increasing the strain rate from about 0·1 to 8 per min. increased the reduction in area from about 10% to about 20%, and they found no embrittlement in impact tests.

It now remains to consider the effect of rest periods on embrittled steel. Atomic hydrogen rapidly diffuses out of the lattice, whereas hydrogen is only removed from crack nuclei very slowly at normal temperatures. The diffusion rate of molecular hydrogen in steel is extremely small. If diffusion in the atomic state is involved, a molecule inside a crack nucleus has to be supplied with an activation energy equal to the difference between the energy of dissociation and the work done by intramolecular forces in the expansion between other molecules to fill the vacant volume of the molecule under consideration. At room temperature little dissociation and diffusion will occur before the process effectively comes to a halt because of the rising energy barrier, and an increase in temperature is required to provide sufficient energy for the process to continue.

The very high incidence of fracture with short delay periods (71%) in the 'hard' clips after storage for 115 days at room temperature may therefore, according to this hypothesis, be related to the effect of residual molecular hydrogen present in structural discontinuities in the steel, which will favour the growth of crack nuclei by processes (ii) and (iii) above. Tempering treatments at fairly low temperatures should provide activation energy for the further outward diffusion of hydrogen with a consequent mitigation of its effects. However, the results obtained with 'hard' clips after tempering at 200° and 250° C., in which the incidence of short-term delays was still high, show that the fracture behaviour has been influenced to some extent irreversibly by the introduction of hydrogen. A possible explanation of such behaviour is that permanent damage to the steel may result from such treatment, crack nuclei having in a number of cases grown from certain favourable discontinuities in the structure, such as inclusions, to near the critical size during the time that hydrogen was present in the steel.

The hardness of the steel plays an important part in determining the short-term delayed-fracture behaviour. A possible reason for this is that the softer steel has sufficient ductility to permit some relief of stress concentration around the edges of crack nuclei to take place and consequently retards their growth. The evidence presented, however, shows that even in the softer steel there is a small but finite number of clips (1–2%) which are permanently affected by cathodic impregnation with hydrogen. The very small percentage of specimens affected in this way suggests that a nucleus of favourable size or disposition is only rarely encountered.

The hypothesis which is advanced enables a generally satisfactory account to be given of the observed results, and the inferences to be drawn are wider than the problem whose investigation initiated the work. The implications may be relevant to the study of the brittle fracture of welded prefabricated structures such as bridges and ships. It is known[10, 11] that hydrogen can be introduced into steel during welding, especially in conditions of high relative humidity, and it is possible that crack nuclei may grow to above the critical size under the influence of stresses due to restraints in the structure. These nuclei may not spread immediately if the stresses are not high, but they will persist in the structure and propagate very much later when the structure is subjected to particularly high stresses in high winds or seas, or when it is made more susceptible to notch effects (*e.g.*, by a fall in temperature to below the brittle–ductile transition for the steel).

Further investigation of these effects is clearly desirable, but such investigation is made difficult by the low incidence of the effects, which demands a statistical approach, especially in soft steels, and by the difficulty of determining the very small amounts of hydrogen which are apparently sufficient to produce the effects.

## Acknowledgments

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# Calculation of Roll Force and Torque in Cold-Rolling by Graphical and Experimental Methods

*By R. B. Sims, B.Sc., A.M.I.Mech.E., A.Inst.P.*

SYNOPSIS

When tensions are not applied in cold strip rolling, solutions of the equations for roll force and torque, in which allowances are made for the elastic distortion of the mill rolls, may be obtained in terms of the ratio roll-radius/entry-strip-thickness, the pass reduction, the yield stress of the material, and the coefficient of friction. These solutions are presented, with an account of the assumptions made in deriving the equations, and the work undertaken to verify them experimentally. An alternative presentation of the solutions of the equations is given in the form of nomograms prepared for individual materials from the data available in the general solution.

The form of the equations leads to a method for estimating the rolling loads and torques in large mills from the results of a few experiments using a smaller mill equipped with roll-force and torque meters. A solution is also provided to the maximum reduction possible on a material in a given mill. 903

MANY methods have been proposed for calculating roll forces and torques in cold reduction mills, but none is at the same time accurate and simple to carry out. From a practical viewpoint the objection to previous theoretical methods is the time needed to reach a solution, particularly when the effect of the elastic deformation of the rolls is considered, as, indeed, it must be if reasonable accuracy is to be achieved. This is because the deformed roll radius and the roll force are interdependent, their values being reached by successive approximations until consistent values of both quantities are obtained. Frequently these approximations converge very slowly and require many recalculations of the roll-force equation. On the other hand there must always be an element of doubt in using the simple empirical or semi-empirical relationships deduced from a narrow range of experimental data, especially where the experimental conditions were different from the pass under consideration.

In this paper is described a rapid, simple, and accurate method of calculation developed during research into production problems in cold-rolling. It will be shown that if the yield-stress/strain relationship for the material and the coefficient of friction in the roll gap are known, a relation may be derived between the roll force, torque, and the geometry of the mill and strip, which includes the effect of roll distortion. The form of the solution is complex, but by presenting it graphically, the roll separating forces and torques for a set of passes may be calculated in a few minutes.

A nomographic solution is also possible, one nomogram being required to calculate roll force and another for the roll torque for each material. A set of nomograms is given for a 0·08% C rimming steel. A curve of mean yield stress *vs.* pass reduction must be added to each nomogram if calculations for the first passes on annealed materials are to be made with the same accuracy as those for the second and subsequent passes.

This solution for the roll load also provides a value of the minimum thickness of strip which may be rolled in a mill. The equations to the roll load and torque and the equations to the minimum thickness have been checked experimentally, and it will be shown that the calculations are in satisfactory agreement with the measured values.

**List of Symbols**

| | |
|---|---|
| $R$ | Radius of the undeformed roll, in. |
| $H$ | Entry thickness of the strip in the pass, in. |
| $h$ | Exit thickness of the strip in the pass, in. |
| $B$ | Width of strip before rolling, in. |
| $P_0$ | Specific roll force when strip is rolled without tension, tons/in. width |
| $G_0$ | Specific torque when strip is rolled without tension, tons-in./in. width, per roll |
| $t_f$ | Forward tension stress on strip, tons/sq. in. |
| $t_b$ | Back tension stress on strip, tons/sq. in. |
| $r$ | Total reduction in thickness in the pass $= (H-h)/H$ |
| $r_1$ | Total reduction from the annealed condition before the pass |
| $r_2$ | Total reduction from the annealed condition after the pass |
| $\bar{r}$ | A mean reduction |
| $\delta$ | Draft, in. |
| $\alpha$ | Angle of contact, radians |
| $\bar{k}$ | Mean yield strength of the material in plane compression, tons/sq. in. |
| $\mu$ | Coefficient of friction |
| $a$ | $\mu\sqrt{(R'/h)}$, a dimensionless parameter |
| | And, for any point on the arc of contact, let |
| $s$ | Pressure normal to the roll surface, tons/sq. in. |
| $\theta$ | Angular co-ordinate, radians |
| $y$ | Thickness of strip, in. |
| $e$ | Reduction $= (H-y)/H$ |
| $R'$ | Radius of curvature of the deformed arc of contact |
| $k$ | Yield strength of the material in plane compression, tons/sq. in. |

Papar MW/A/4/53 of the Rolling Committee of the Mechanical Working Division of B.I.S.R.A., received 28th October, 1953. The views expressed are the author's, and are not necessarily endorsed by the the Committee as a body.

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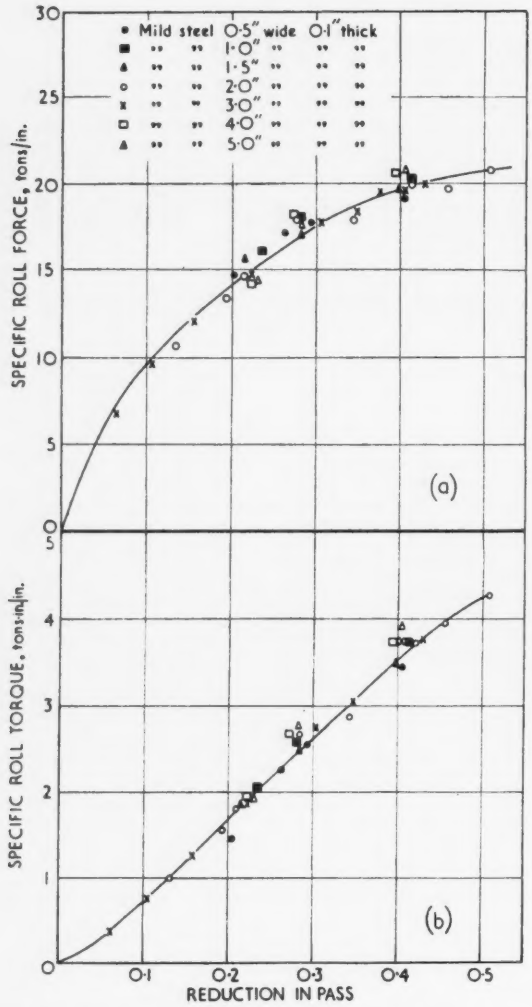

• Mild steel 0·5" wide 0·1" thick
■ " " 1·0" " "
▲ " " 1·5" " "
○ " " 2·0" " "
× " " 3·0" " "
□ " " 4·0" " "
△ " " 5·0" " "
SPECIFIC ROLL FORCE, tons/in.
(a)
SPECIFIC ROLL TORQUE, tons-in/in.
(b)
REDUCTION IN PASS

**Fig. 1—Effect of strip width on (*a*) specific roll force, (*b*) specific roll torque**

Suffixes 1 and 2 refer to the entry and exit side of the roll gap, respectively; $\theta$ is measured from the centre of curvature of the deformed arc, and is assumed to be small enough to write without great error $\sin\theta = \theta$ and $\cos\theta = 1$, except for the term $(1-\cos\theta)$ which is taken as $\frac{1}{2}\theta^2$.

## ASSUMPTIONS MADE IN DERIVING THE EQUATIONS

The exact solution has yet to be found for the slip-line field in the plastic material between the rolls of a mill. In providing a simple and rapid method for computing roll force and torque, assumptions have been made which inevitably affect the final accuracy. These assumptions, and the rolling conditions where they may be considered reasonable, will now be discussed.

### Plane Deformation

Most equations for the roll force and torque in cold-rolling assume that plane deformation occurs, *i.e.*, all lateral strain in the material is inhibited and parallel cross-sections in the material before rolling remain parallel after rolling. The lateral spread is small in strip-rolling where the width/thickness ratio of the material is large. For example, in a pass in which a 54% reduction was taken on an annealed mild-steel strip with width/thickness ratio of 50, the spread was less than 1% of the width.

An experimental investigation made by Baker, Ricksecker, and Baldwin[1] has shown that when the ratio of the length of the arc of contact to the exit thickness of the strip ($L/h$) is greater than 3, the deformation across a section of the material is very nearly uniform. This can be true only when the tangential stress on the material due to rubbing friction at the roll surface is substantially less than the yield stress in shear. In most strip-rolling the spread is small, the ratio $L/h$ large, and there is slipping friction between the rolls and the material, so that the actual deformation may be represented closely by a model in which plane deformation is assumed to take place.

### Variation of Roll Force and Torque with Strip Width

It will be assumed that the roll load and the applied torque vary linearly with the initial width of the strip. Equations have been derived, therefore, for the calculation of the roll force and the torque per roll for unit (inch) width of strip, quantities which will be referred to as the specific roll force and torque.

Experiments made by Siebel and Lueg[2] and more recently by Smith, Scott, and Sylwestrowicz[3] indicate that the roll pressure decreases considerably near the edges of the strip. The roll force, which is an integration of roll pressure over the arc of contact, will vary linearly with width only when the strip is sufficiently wide in comparison with its thickness for these edge effects to become negligibly small. To determine the minimum value of the strip-width/thickness ratio ($B/H$) at which the assumption of linearity is reasonable, strips 0·104 in. thick and 0·5–5 in. wide were cut from a single coil of annealed mild steel, and rolled without tension to reductions varying from 5% to 50% in one pass in the 10 in. × 10 in. 2-high experimental mill at Sheffield University. The results are given in Fig. 1*a* for specific roll force and Fig. 1*b* for the specific roll torque. The maximum variation in

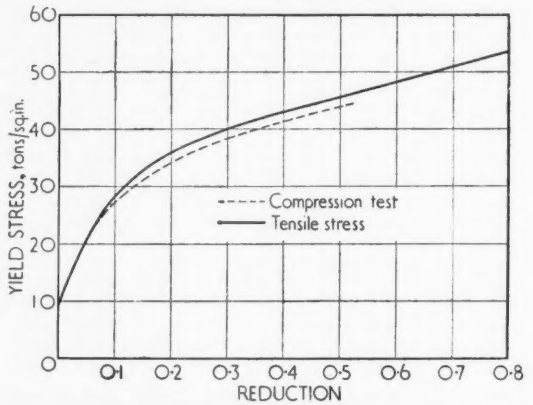



**Fig. 2—Yield stress of mild steel (about 0·08% C) in plane compression**

specific roll force is $\pm 3\%$ of the mean value, which is well within the known experimental errors due to instrument inaccuracies and variations due to lubrication. There appears to be no systematic change in either specific roll force or torque with strip width at any reduction. Lueg and Pomp, however, in earlier research[4] found that the specific roll pressure, a function allied to the specific roll load, was linear with width only when $B/H$ exceeded 15. A linear relationship between load and strip width at values of $B/H \leqslant 1$ has been observed during hot-rolling research,[5] attributable to the increase in the arc of contact area due to spread compensating for the edge effect.

To the order of accuracy attempted by the present method of calculation, therefore, linearity may be assumed between roll force, torque, and strip width for values of $B/H$ exceeding 10.

#### Yield Stress of the Material

It is well known industrially that variations in the mechanical properties are common between specimens of the same chemical composition. On the other hand, it is unlikely that in production mills a yield-stress/strain curve covering the entire range of reductions taken will be available for every coil before it is rolled. The yield-stress/strain curve has been measured for each coil used in the experimental work, but in designing the nomograms which are intended chiefly for use in the mill, it was considered that the assumption of a single yield-stress/strain curve as representative of a particular material would not involve errors unacceptable to industry.

Since the lateral strain in strip-rolling is negligibly small in comparison with the reduction in strip thickness, the yield stress of the material in plane compression is required for the calculation of the specific roll force and torque. A description for an experimental method for determining the yield stress in plane compression and data for a number of commonly rolled metals are given in a companion paper.[6] The yield-stress/strain curve for rimming steel obtained by the method described, and used in the preparation of the nomogram, is shown in Fig. 2.

The strain hardening which occurs in the material during rolling is allowed for by employing mean yield stresses in the calculation of specific roll force and torque. The use of a mean value cannot be justified rigorously, but in the case of roll-force calculation it has been shown that an error of less than $\pm$ 2% is introduced by its use. The equation for the mean yield stress is discussed later.

#### Elastic Distortion of the Rolls

The work rolls of a mill are compressed by the load in the roll gap and the thrust of the screws applied either at the roll necks in the case of the 2-high mill or by the back-up rolls in 4-high designs. The resulting elastic deformation has two quite distinct effects on the rolling process. Firstly, the rolls in deforming as a whole contribute to the mill spring and, therefore, to the variations in rolled-strip thickness in the manner discussed by Hessenberg and Sims.[7] Secondly, the curvature of the loaded surface is altered, thereby increasing the rolling load.

The elastic deformation of the rolls influences the rolling load by lengthening the arc of contact and,

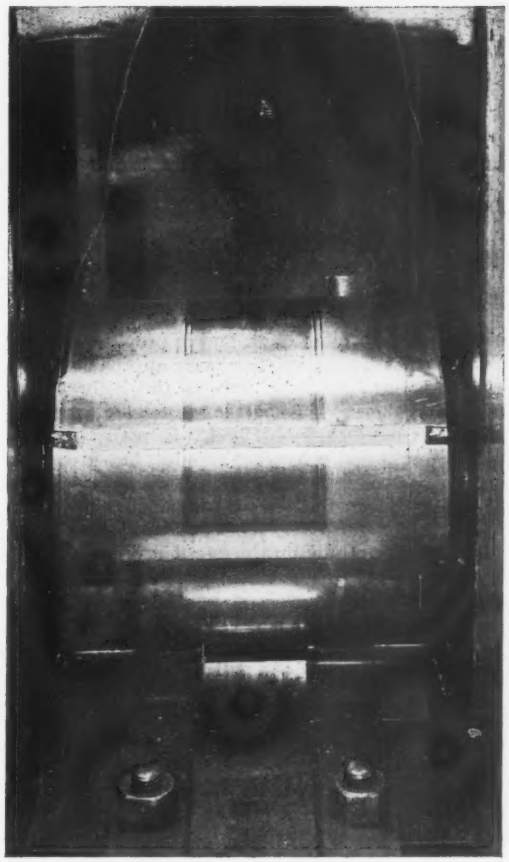


**Fig. 3—Gauge for determining time of contact**

effectively, increasing the roll-radius/entry-thickness ratio ($R/H$). A practical method of allowing for this roll deformation is due to Hitchcock,[8] who replaced the actual pressure by an elliptical distribution giving the same specific roll force. The radius of curvature of the rolls is then constant, and from Prescott's equations to a cylindrical surface deformed by an elliptical pressure distribution, Hitchcock derived an equation which may be rewritten in the simpler form :

$$R' = R\left(1 + \frac{cP}{\delta}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where $c$ is the constant depending on the elastic constants of the roll material. For steel rolls, $c = 3{\cdot}45$ sq. in./ton. An accurate calculation of the curvature of a loaded roll is possible but the labour involved is heavy. A method of computation has been given by Bland,[9] who concluded that in the calculation of roll loads, little additional accuracy could be achieved by using it in place of the far simpler method due to Hitchcock. Bland also showed that Hitchcock's value of the roll radius does not differ sufficiently from the true radius of curvature to affect materially the value of the parameter $R/H$ which enters the calculation of roll load and torque.

As mentioned in the introduction, the roll radius calculated from Hitchcock's equation and the specific

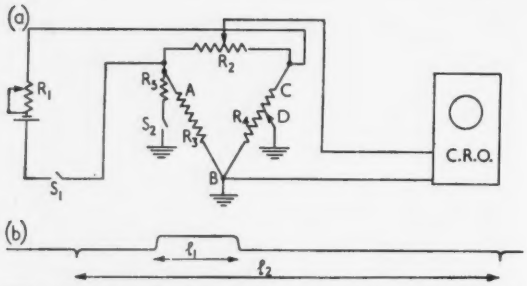


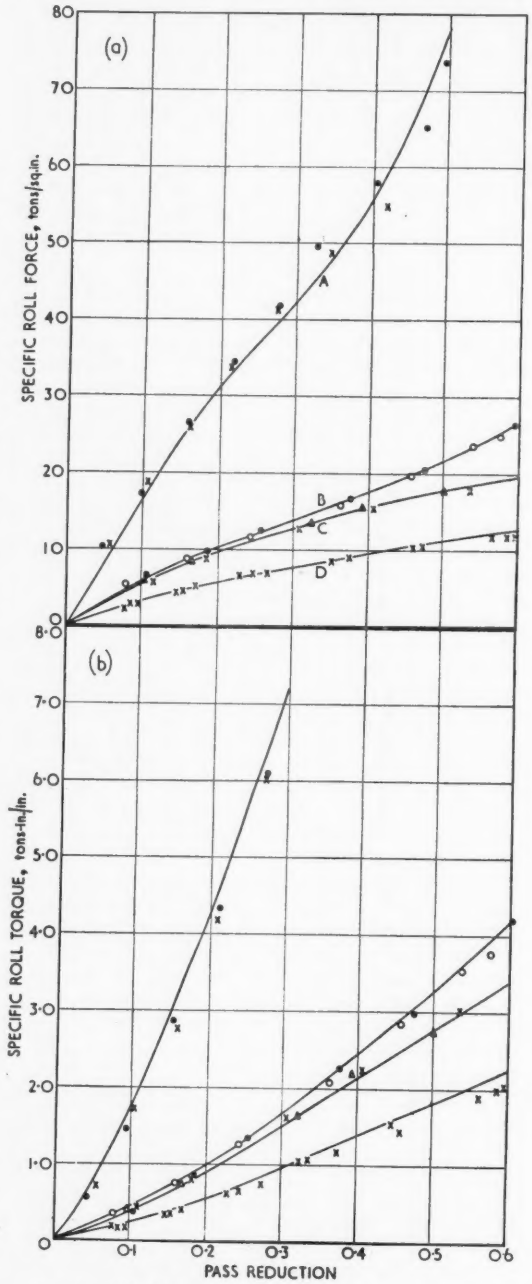

**Fig. 4—Determination of time of contact: (*a*) Wheatstone bridge circuit; (*b*) typical record**

roll load are interdependent, and in previous methods of calculation a solution has been approached by a series of approximations, first to the deformed-roll radius, and then to the specific roll load until consistent values have been obtained. In many instances the approximation converges rapidly, but in calculations on the rolling of thin hard strip between work rolls of large diameter, the convergence is slow, and is sometimes non-existent. This will be discussed later in dealing with minimum thickness in rolling.

It is of interest to note that other calculations of roll curvature by Hitchcock and by Föppl gave similar results when assuming a parabolic and square pressure distribution; hence it would appear that the elastic deformation of the rolls is not greatly sensitive to the form of the actual pressure distribution. There are formidable difficulties in carrying out an experimental determination of the curvature of the deformed roll. An attempt has been made by Orowan,[10] who stopped his experimental mill with the material between the rolls and then lifted the rolls clear as quickly as possible. The curvature of the strip left in the rolls was measured, and taken to be equivalent to that of the deformed roll. The objection to this method is that when the mill is brought to rest the frictional component of the pressure distribution cannot be maintained and the deformation of the plastic material between the rolls will conform to the changed distribution, and will not be related to the roll curvature during the pass.

The following experiments were carried out to determine the length of the arc of contact, for in the calculation of roll force and torque it is of greater importance than the exact values of the roll curvature along the arc of contact.

To measure the length of the arc of contact an indication is required of the length of time a point on the roll surface is in contact with the material, and also the speed of rotation of the rolls. The time of contact was obtained from a fine wire gauge bonded to the roll surface. It consisted of a length of Eureka ribbon about 0·001 in. thick and 0·015 in. wide cemented between two strips of paper, one of which had a small perforation at its centre. The whole gauge was cemented to the face of the upper roll parallel with the roll axis with the perforation outwards, as shown in Fig. 3. A dummy gauge was bonded in the corresponding position on the lower roll to keep the rolling conditions uniform in the arc of contact. The ribbon was connected to form one arm *BC* of a Wheatstone bridge circuit (Fig. 4*a*). When the ribbon entered the contact arc, the exposed wire at the centre of the gauge made contact with the rolled material and so earthed the network through the mill structure. The point *B* of the arm was connected permanently to earth so that while the ribbon was in




*A* = Annealed stainless steel ($\mu = 0{\cdot}08$); *B* = Annealed mild steel ($\mu = 0{\cdot}08$);
*C* = Annealed mild steel ($\mu = 0{\cdot}05$); *D* = Annealed copper ($\mu = 0{\cdot}07$)

**Fig. 5—Measured values (shown as points) compared with calculated values (full lines) for (*a*) roll force and (*b*) roll torque**

the contact arc the resistance $R_4$ of the arm $BC$ was reduced to $\frac{1}{2}R_4$. The adjacent arm $AB$ had end $A$ connected to earth through a contact $S_2$ and a resistance $R_5$ which was approximately equal to $R_3$. The contact $S_2$ was closed for a short time during each revolution of the mill motor, thus momentarily reducing the resistance of arm $AB$ from $R_3$ to $R_3$ and $R_5$ in parallel. If the bridge is initially balanced the two events described will unbalance the bridge in opposite senses producing potential differences of opposite sign at $BD$. This potential difference was applied to an amplifier of the modulated carrier type having substantially flat response from D.C. to 5000 cycles/sec. The output of this amplifier was fed to the $Y$-plates of a cathode-ray oscilloscope which was photographed with a continuous-feed ciné camera which provided the time base. A typical record is reproduced in Fig. 4*b*. This record, together with a knowledge of the gear ratio from mill to rolls, enabled the angular length of the contact arc to be measured directly.

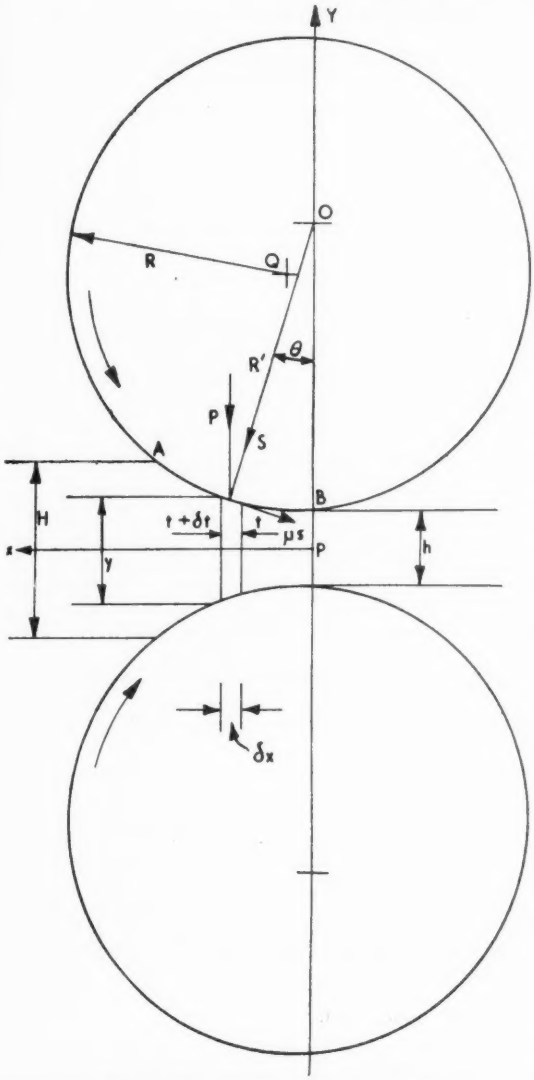



**Fig. 6—Forces acting on the strip**

**Table I**

**MEASURED AND CALCULATED VALUES OF ARC OF CONTACT**

| Initial Thickness $H$, $10^{-4}$ in. | Draft $\delta$, $10^{-4}$ in. | Specific Roll Load $P_0$, tons/in. | Angular Contact Arc $\alpha$, radians | |
|---|---|---|---|---|
| | | | Measured | Calculated |
| 619 | 119 | 11·8 | 0·049 | 0·056 |
| 616 | 116 | 11·5 | 0·052 | 0·055 |
| 425 | 80 | 14·4 | 0·056 | 0·051 |
| 613 | 127 | 12·9 | 0·053 | 0·058 |
| 614 | 173 | 14·4 | 0·064 | 0·067 |
| 297 | 25 | 10·6 | 0·039 | 0·035 |

The strips used were of rimming steel 2·5 in. and 3·5 in. wide, 24 in. long and of various thicknesses obtained by rolling from annealed stock 0·064 in. thick.

The experimental results, corrected for the finite thickness and width of the gauge wire, are given in Table I, together with the corresponding values calculated from equation (1). It will be seen that there is no large systematic error between the calculated values and the experimental results, and it is concluded that, over the range of rolling conditions covered by the experiments, Hitchcock's equation gives a reasonable correction for the elastic deformation of the rolls in a calculation of roll force and torque.

### Elastic Recovery of the Strip

In equations of rolling it is assumed that there is no elastic deformation in the material prior to plastic straining and after the plastic distortion has ceased and the load is removed. This assumption of an ideal plastic-rigid material is not altogether justified and Bland and Ford[11] have given an approximate correction for its effect on load. The correction is generally very small over the range of reductions covered by the present method of calculation, and has been neglected. It may be important in calculating loads in temper-pass mills and when strip is rolled near its limiting reduction (*q.v.*) and should be included in any accurate calculation of specific roll load.

### Rolling Friction

In cold-rolling, a lubricant is usually applied to the material to prevent its adhering to the roll surface, and the rolls and strip slip over each other at a speed which varies from point to point along the arc of contact. When rolling coils in the 2-high experimental mill it was found that the coefficient of friction, although usually constant for a single coil* of material, may vary considerably from coil to coil even when the rolling conditions are otherwise similar, and Sims and Arthur[13] have shown that it decreases consistently as the mill speed is increased.

A direct measurement has not been made of the

*An experiment has been described[12] where irregular changes in friction were observed when rolling a coil at a fixed roll setting and mill speed. These variations were small, however, when compared with the changes in strip friction which occur from coil to coil of the same material rolled under apparently identical conditions.

magnitude of the coefficient of friction between the rolls and strip. In the following analysis it is assumed that the coefficient of friction remains constant over the arc of contact. This can only be justified indirectly by comparing calculations of specific roll force and torque in which the assumption is made, with measured values over a wide range of reductions and materials when rolling at a constant speed. In Figs. 5*a* and *b* this has been done for coils of annealed stainless steel rolled with palm oil lubrication, annealed rimming steel rolled with a soluble oil emulsion, and for a coil of annealed high-conductivity copper also lubricated with soluble oil emulsion. The agreement is close and suggests that a constant coefficient of friction provides a model of the pressure distribution in the arc of contact which is sufficiently close to the actual distribution to give reliable values of roll force and torque.

Numerous tests in the laboratory and on mills in production have led to the conclusion that with a surface finish to the rolls between about 10 and 20 microinches the coefficient of friction for mild steel lubricated with commercially available rolling oils and rolled at speeds below 50 ft./min. has an average value of 0·08, which decreases as the mill is accelerated, and for mills at higher speeds a value between 0·05 and 0·03 is appropriate. The coefficient of friction is generally reduced by the use of mirror-finished rolls. Similar values have been found for stainless steel and copper in the experimental mill. Accordingly, numerical solutions for roll force and torque have been obtained for $\mu = 0{\cdot}12$, $0{\cdot}08$, and $0{\cdot}05$. It is suggested that unless a reliable estimate of the coefficient of friction is available the solution calculated for $\mu = 0{\cdot}08$ is used for general mill design and the solution with $\mu = 0{\cdot}05$ is used for calculations on mills at high rolling speeds. When a reliable estimate of the coefficient of friction in the pass is available, an interpolation may readily be made from the values of specific roll force and torque obtained from the three sets of numerical values.

The mechanism of the changes in friction observed in rolling has been discussed by Sims,[14] where the suggestion is made that, except in the neutral plane, the coefficient of friction remains constant in the arc of contact at a value dependent on the rheological properties of the solid deposit laid down on the strip by the lubricant.

## EQUATIONS FOR SPECIFIC ROLL FORCE

Modern theories of rolling are based on Karman's equation to the equilibrium of forces acting on the strip, combined with one or other of the criteria for plastic yielding. These forces are shown diagrammatically in Fig. 6. The polar co-ordinates have a pole at $O$, the centre of curvature of the arc of contact $AB$, and the rectangular co-ordinates have as origin the centre of the strip in the plane of exit. The equation to the horizontal equilibrium of the forces on an element of unit width, thickness $y$, and length $dx$ has been given by Karman as:

$$s(\tan\theta \mp \mu) + \tfrac{1}{2}\, d/dx\,(ty) = 0 \quad \ldots\ldots(2)$$

The sign $\mp$ in the first term arises from the fact that from the plane of entry ($\theta = \alpha$) the roll moves faster than the strip until at some point ($\theta = \phi$) the rolls and strip move together. From this ' neutral plane ' to the plane of exit, the strip moves faster than the rolls.

It follows, therefore, that from the plane of exit to the neutral point, the frictional forces on the strip are in the direction of rolling, and from the neutral plane to the plane of exit, the friction opposes the motion of the strip. At the neutral plane the frictional forces (which are at a maximum value) are reversed in sign. The physical interpretation of this (mathematical) assumption has been discussed by Sims.[14] The two solutions of equation (2) are independent, and intersect when $\theta = \phi$. The most accurate solutions of equation (2) are due to Orowan.[10] Assuming uniform deformation and the Huber–Mises equation to yielding in plane compression, he obtained

$$\frac{d}{d\theta}(ty) = 2R'(k + t)\tan(\theta \mp \mu)\cos\theta \quad \ldots\ldots(3)$$

which can only be solved for the vertical pressure by a tedious step-by-step integration. Bland and Ford[15] re-wrote the equation in terms of the roll pressure, and assumed that

$$yk\frac{d}{d\theta}\left(\frac{s}{k}\right) \geqslant \left(\frac{s}{k} - 1\right)\frac{d}{d\theta}(yk) \quad \ldots\ldots(4)$$

and reduced it to an integrable form. With the further assumption that $\sin\theta \simeq \theta$, etc., they derived the equations

$$s = \left(1 - \frac{tb}{k_1}\right)\frac{ky}{H}\exp[\mu F(\alpha) - \mu F(\theta)] \quad \ldots\ldots(5)$$

for all values of $\alpha \geqslant \theta \geqslant \phi$, and

$$s = \left(1 - \frac{tf}{k_2}\right)\frac{ky}{h}\exp[\mu F(\theta)] \quad \ldots\ldots(6)$$

for all values of $\phi \geqslant \theta \geqslant 0$, where

$$F(\theta) = 2\sqrt{(R'/h)}\tan^{-1}\sqrt{(R'/h)}\theta \quad \ldots\ldots(7)$$

For rolling without applied strip tensions Bland and Ford[15] showed that these equations were capable of reasonable accuracy both in comparison with Orowan's solution and with the results of experiments. For rolling with tensions, however, considerable errors were introduced due to assumption in equation (4), particularly when rolling annealed materials with high back tension, as Hessenberg and Sims[16] have shown.

Using equations (5) and (6) Bland and Ford tabulated the solution of equation to roll force and torque materials of constant yield stress rolled without tensions, writing :

$$P_0 = k\sqrt{(R'\delta)}.f_P(a, r) \quad \ldots\ldots(8)$$

$$G_0 = (RH^2/h)k\,f_G(a, r) \quad \ldots\ldots(9)$$

where $a = \mu(\sqrt{R'/h})$, a dimensionless parameter, and $f_P(a, r)$ and $f_G(a, r)$ are integrals of both $a$ and $r$ allowing for strip friction in roll force and torque.

The equations may be used for materials which strain-harden by using a mean value of the yield stress, which will be written as $\bar{k}_P$ for roll force and $\bar{k}_G$ for torque.

### Equations for $P_0 r/\bar{k}_P H$

Equation (8) may be written :

$$\frac{P_0}{\bar{k}_P H} = \frac{a}{\mu}\sqrt{[r(1-r)]}f_P(a, r) \quad \ldots\ldots(10)$$

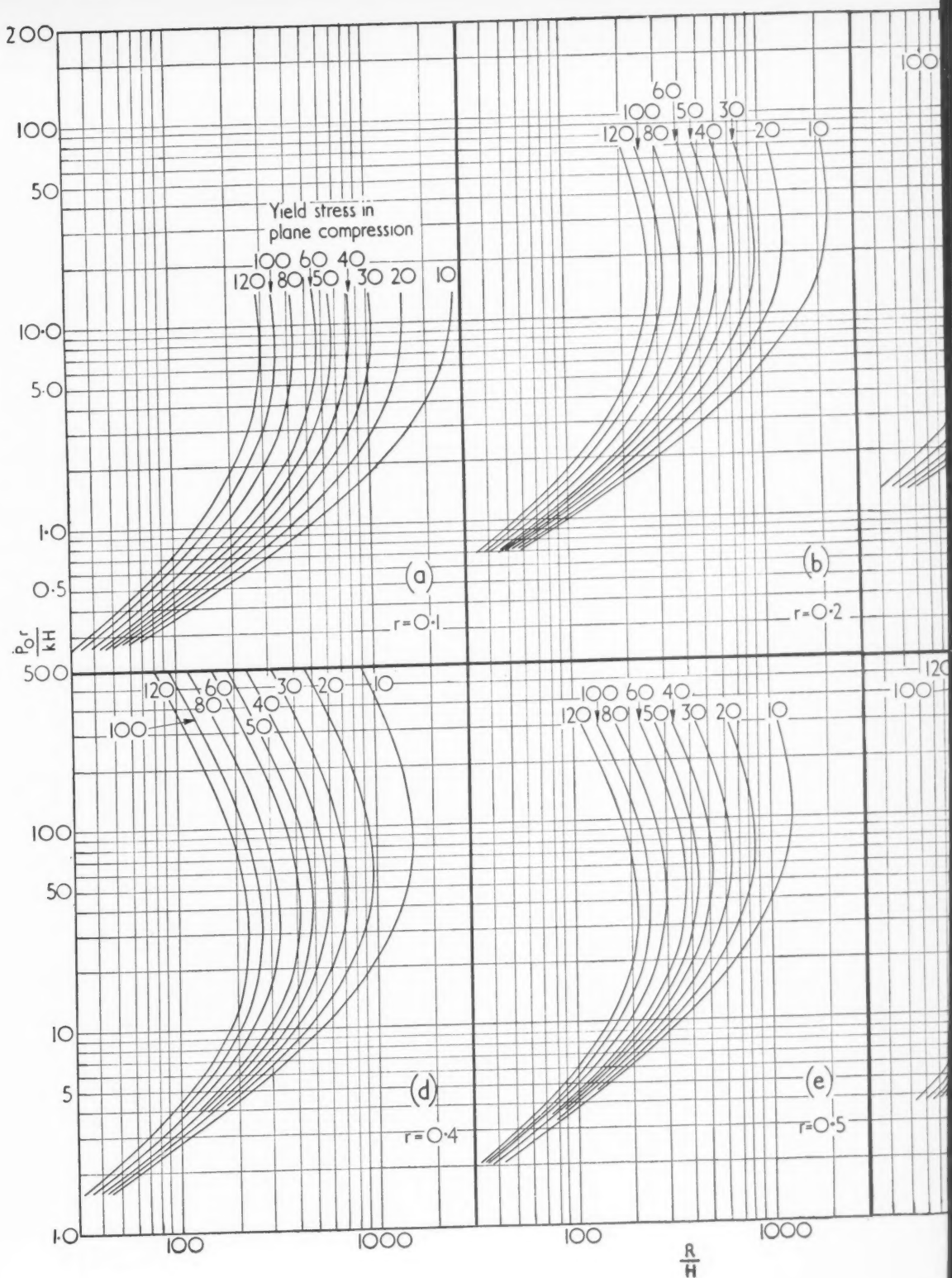
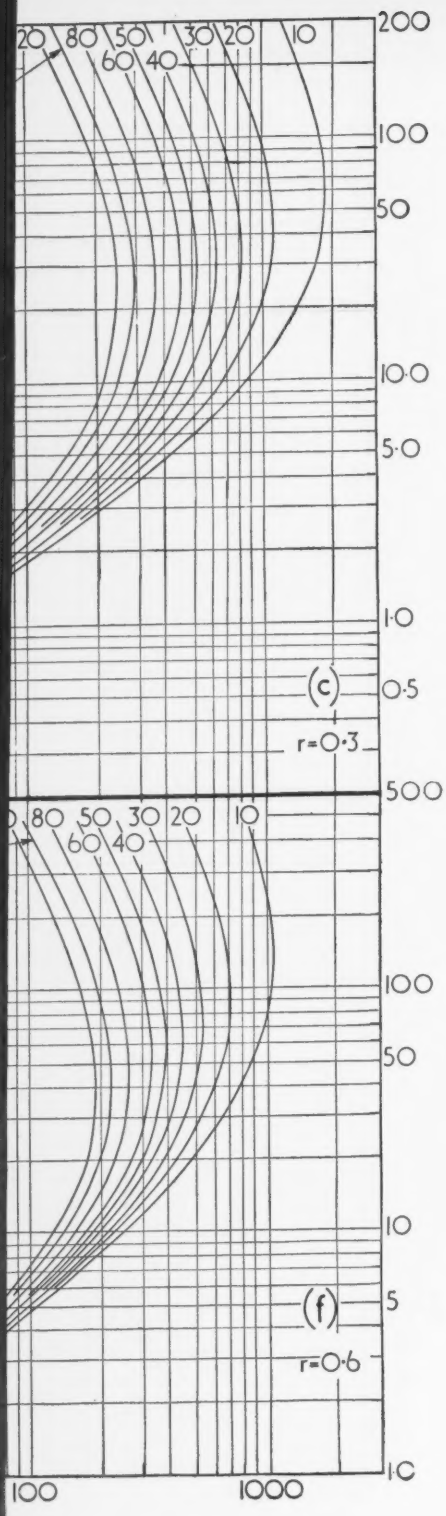



**Fig. 7—Solutions of equations (10)–(12) for $\mu = 0{\cdot}05$**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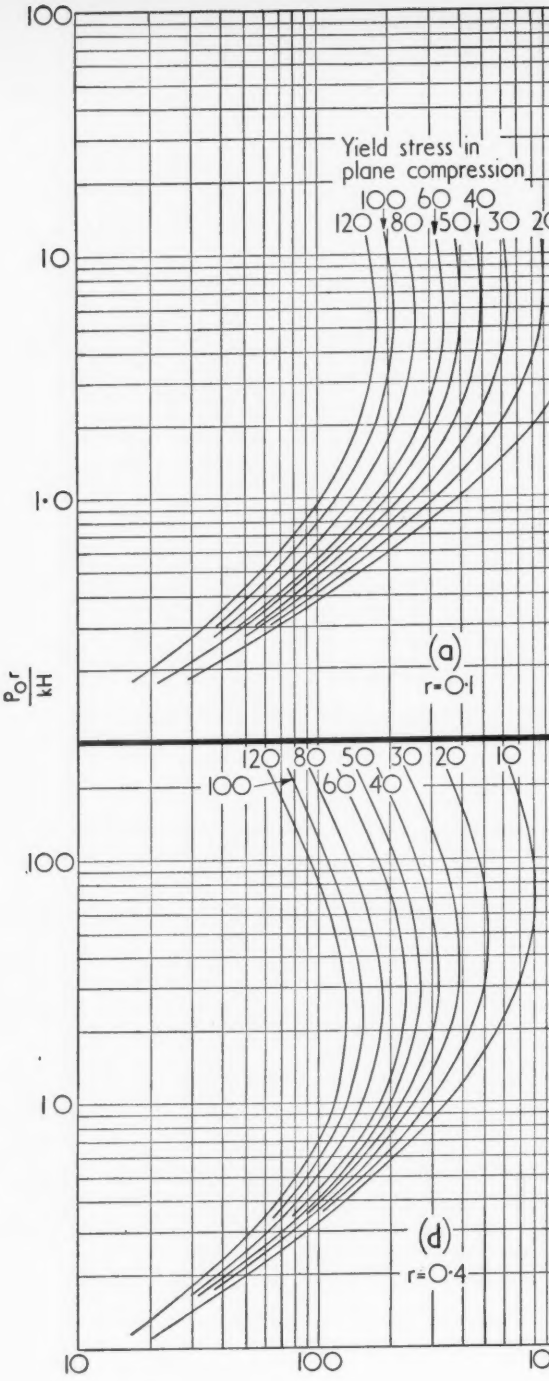
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Yield stress in plane compression
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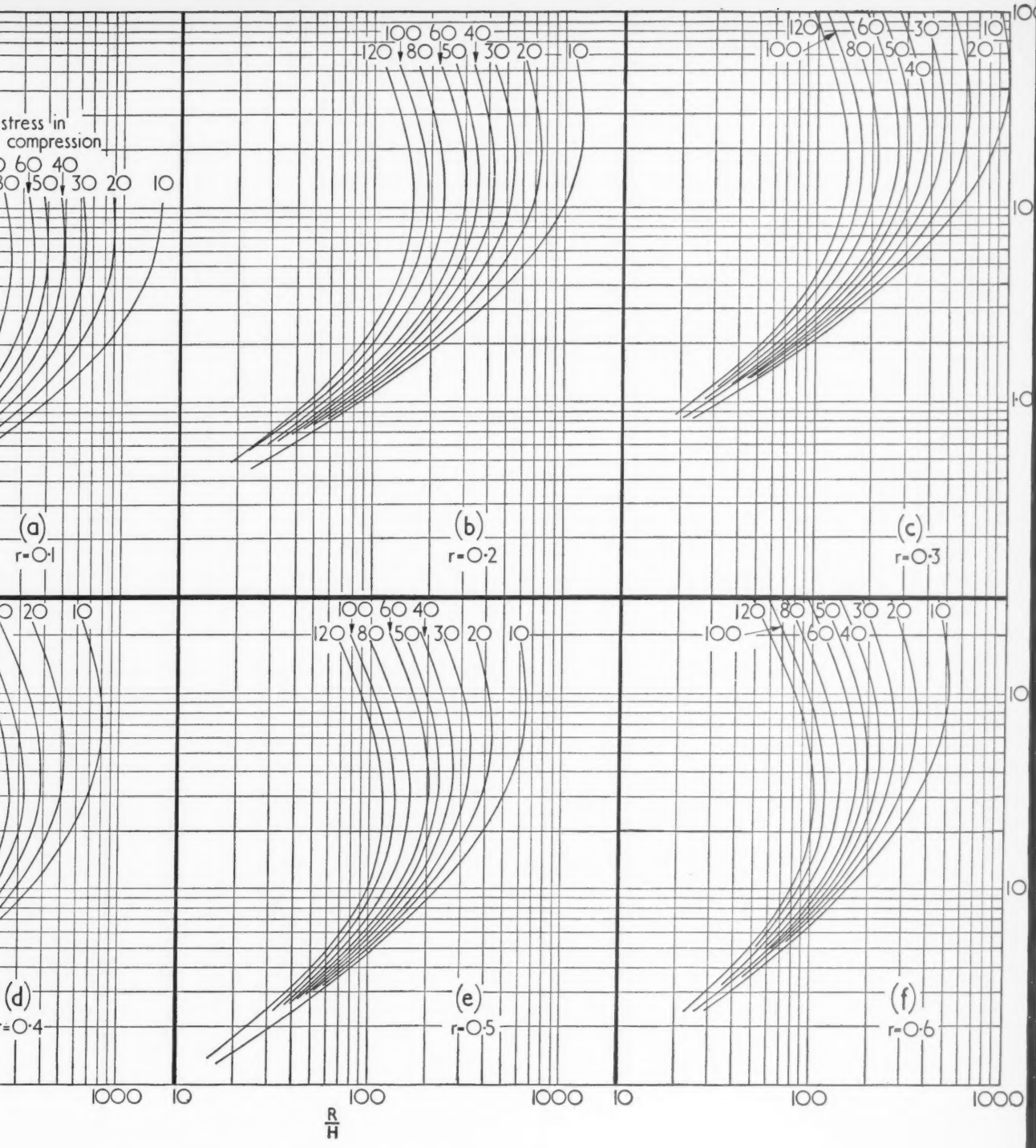


**Fig. 8—Solutions of equations (10)–(12) for $\mu = 0{\cdot}08$**

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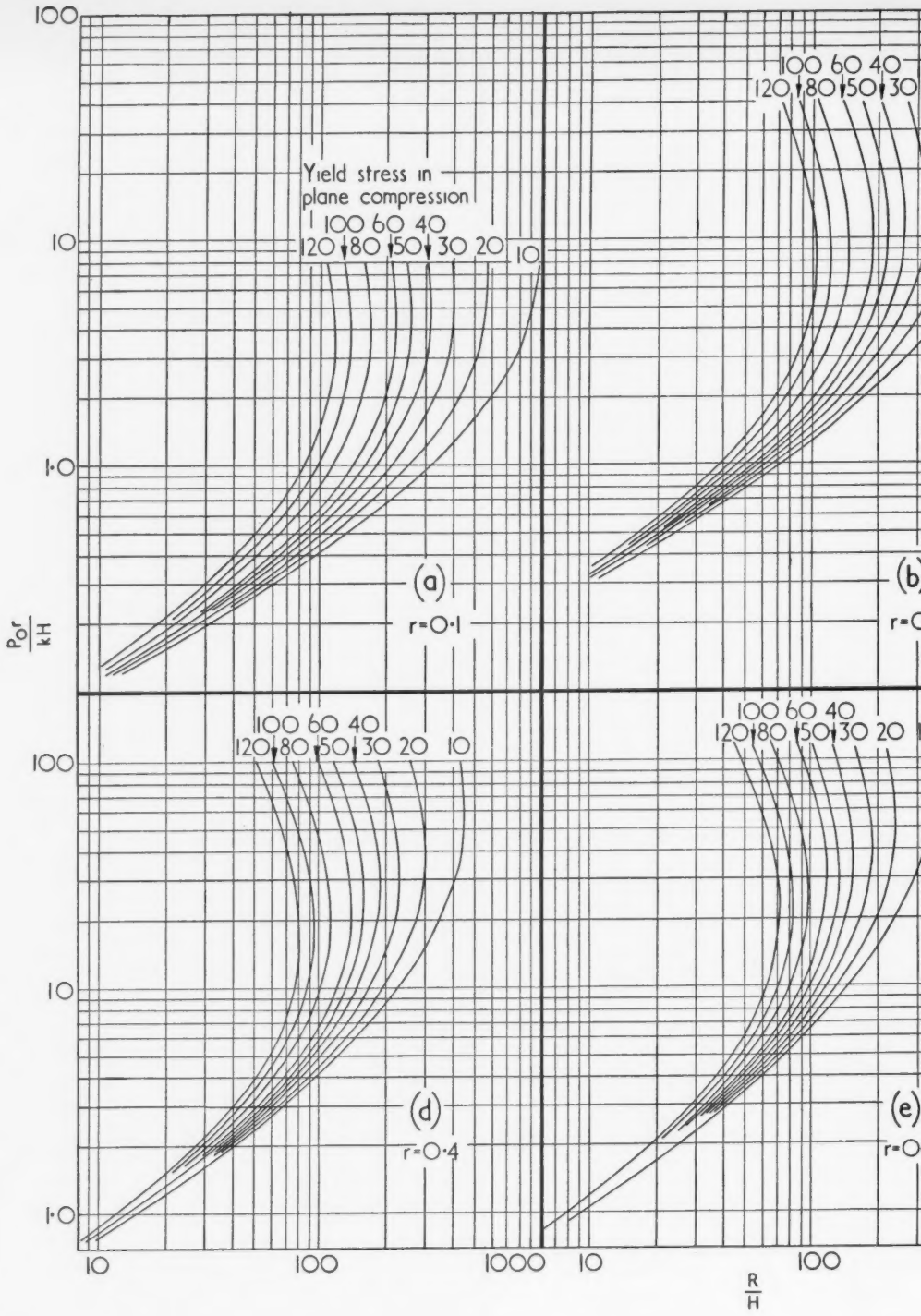


Fig. 9—Solutions of equations (10)–(12) for

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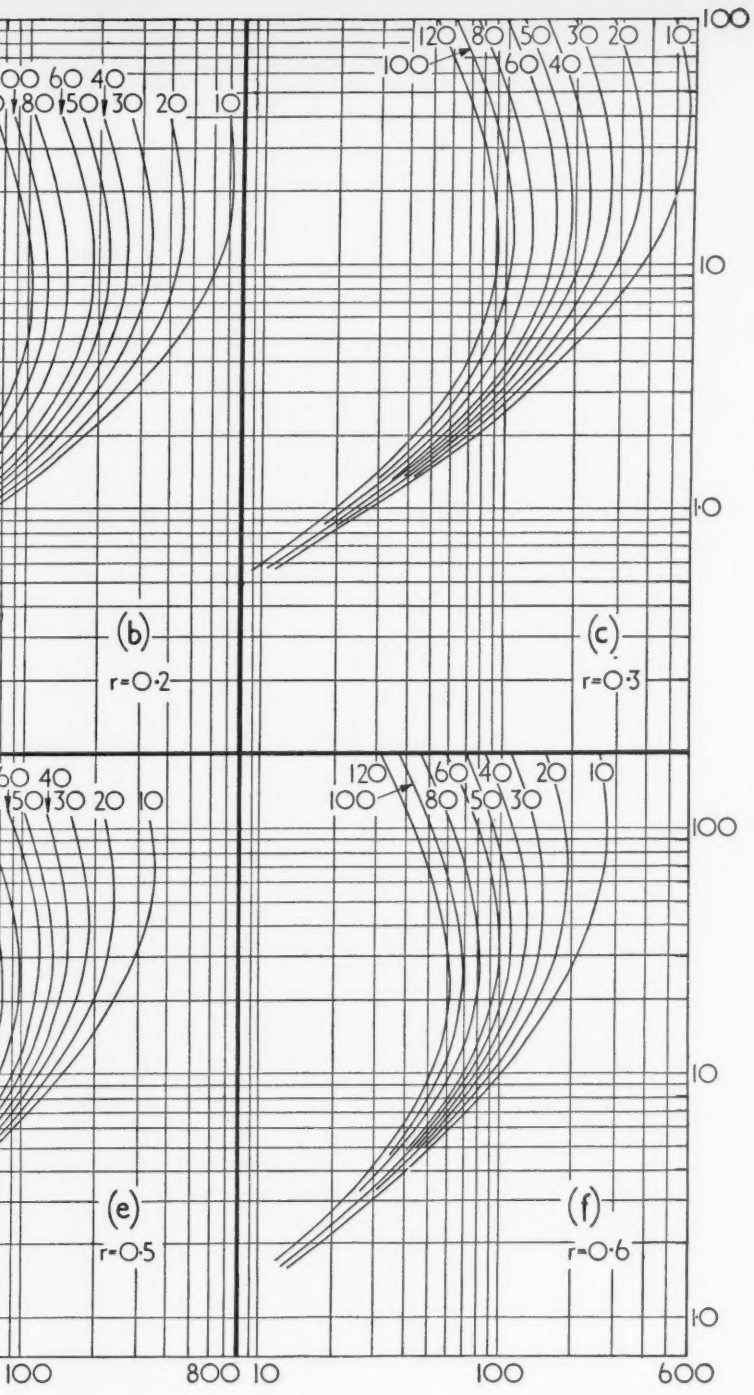


(10)–(12) for $\mu = 0{\cdot}12$

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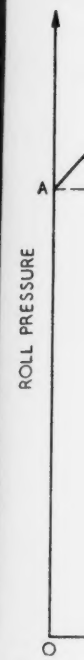


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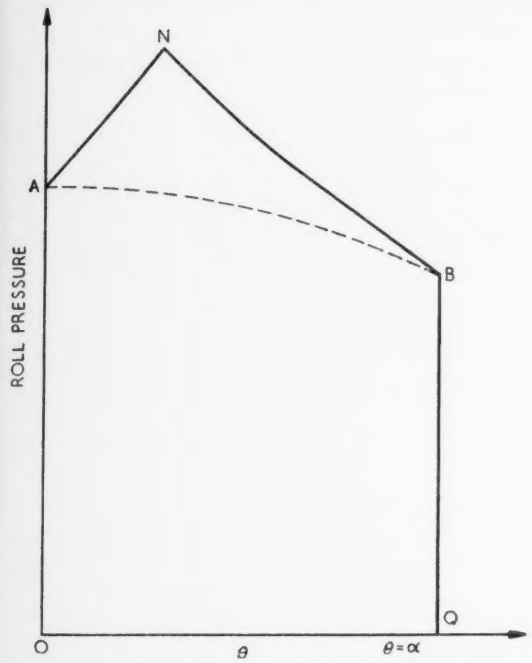



**Fig. 10—Angular distribution of roll pressure in arc of contact**

Hitchcock's formula for the deformed roll radius is:

$$\frac{R'}{R} = 1 + \frac{cP_0}{\delta}$$

where $c = 3{\cdot}45 \times 10^{-4}$ ton/in. for steel rolls, hence

$$\frac{R'}{R} = 1 + \frac{c}{r}\left\{\bar{k}_P \frac{a}{\mu}\sqrt{[r(1-r)]}\, f_P(a,r)\right\} \quad \ldots\ldots\ldots\ldots (11)$$

and finally

$$\frac{R}{H} = \frac{R}{R'} \cdot \frac{R'}{H} = \frac{a^2}{\mu^2}(1-r)\frac{R}{R'} \quad \ldots\ldots\ldots\ldots (12)$$

From equations (10), (11), and (12), the quantity $P_0 r/\bar{k}_P H$ may be expressed in terms of the variables $R/H$, $r$, $\bar{k}_P$, and $\mu$ only. A solution* has been obtained for reductions between 10% and 60%, mean yield stresses between 10 and 120 tons/sq. in., $\mu =$ 0·05, 0·08, and 0·012, and a wide range of values of $R/H$. The completed solution, forming a grid from which nomograms may be constructed, is given in Figs. 7–9.

*The initial calculations were made in the laboratories of the British Iron and Steel Research Association and completed by the Mathematics Division of the National Physical Laboratory under the supervision of Mr. T. Vickers.

**Table III**

**CALCULATION OF $\bar{k}_G$ FOR 50% REDUCTION ON ANNEALED MILD STEELS**

| Reduction | Yield Stress at the Mean Reduction in Interval $k$, tons/sq. in. | Interval in Reduction, % | $de$ (Fractional) | $kde$, tons sq. in. |
|---|---|---|---|---|
| 0 | | | | |
| 5 | 20·1 | | | |
| 10 | | 0–10 | 0·1 | 2·01 |
| 15 | 32·9 | | | |
| 20 | | 10–20 | 0·1 | 3·29 |
| 25 | 38·0 | | | |
| 30 | | 20–30 | 0·1 | 3·80 |
| 35 | 41·5 | | | |
| 40 | | 30–40 | 0·1 | 4·15 |
| 45 | 44·3 | | | |
| 50 | | 40–50 | 0·1 | 4·43 |

### Mean Yield Stress

The equation for roll pressure may be written in the form

$$s = kF(a, \theta/\mu)$$

where $F\ (a,\ \theta/\mu)$ is a factor providing for the effect of strip friction on the roll pressure. The specific roll force is proportional to the area enclosed by the curve in Fig. 10 of the angular distribution of roll pressure, which may be divided into the area $OABQ = \int_0^\alpha kd\theta$ due to the resistance of the material to deformation, and the area $ABN$ due to the rolling friction. The mean yield stress which replaces the actual yield stress of the material along the arc of contact must, therefore, provide an area equal to $OABQ$, and will give a close approximation to the specific roll force only if $F(a,\ \theta/\mu)$ is relatively insensitive to the actual distribution of yield stress.

If $\bar{k}_P$ is the mean yield stress, then from the above reasoning:

$$\alpha\bar{k}_P = \int_0^\alpha kd\theta$$

and hence $\bar{k}_P = 1/\alpha\int_\alpha^0 kd\theta$ ..... (13)

Bland and Ford have shown by direct comparison

**Table II**

**CALCULATION OF $\bar{k}_P$ FOR 50% REDUCTION ON ANNEALED MILD STEEL**

| Reduction, % | Yield Stress at Value of Reduction, tons/sq. in. | $dk$, tons/sq.in. | Interval of Reduction | Mean Values | | | $\sqrt{(r-e)}.dk$, tons/sq. in. |
|---|---|---|---|---|---|---|---|
| | | | | $e$ | $(r-e)$ | $\sqrt{(r-e)}$ | |
| 0 | 10 | | | | | | |
| 10 | 29·8 | 19·8 | 0–10 | 0·05 | 0·45 | 0·671 | 13·50 |
| 20 | 35·8 | 6·0 | 10–20 | 0·15 | 0·35 | 0·592 | 3·55 |
| 30 | 39·8 | 4·0 | 20–30 | 0·25 | 0·25 | 0·500 | 2·50 |
| 40 | 43·0 | 3·2 | 30–40 | 0·35 | 0·15 | 0·387 | 1·24 |
| 50 | 45·7 | 2·7 | 40–50 | 0·45 | 0·05 | 0·224 | 0·60 |

that this value of the mean yield stress gives a close approximation to the specific roll force, and so it may be concluded that the factor $F(a, \theta/\mu)$ is not sensitive to the yield stress.

Equation (13) may be conveniently rewritten. From the geometry of the pass the thickness of the strip $y$ at any point on the arc of contact is given by:

$$y = h + R'\theta^2$$

and by definition, $e = (H-y)H.$

Hence $$e = r-(R'/H)\theta^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(14)$$

$\therefore$ $$\theta^2 = (r-e)H/R' \quad \ldots\ldots\ldots\ldots\ldots\ldots(15)$$

from which $$\frac{\partial e}{\partial \theta} = 2\sqrt{\frac{R'}{H}}\,(r-e) \quad \ldots\ldots\ldots\ldots\ldots\ldots(16)$$

On substituting from equations (14), (15), and (16) into equation (13) and rearranging :

$$\bar{k}_P = 1/\sqrt{r}\left[k_1\sqrt{r}+\int_0^r (r-e)\,dk\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots(17)$$

which may readily be solved over a range of reductions from an experimentally determined yield-stress/strain curve. An example of the calculation is given in Table II.

Total of last column $= \int_0^r \sqrt{(r-e)}dk = 21{\cdot}39$ tons/sq. in.

$k_1\sqrt{r} = 7{\cdot}07$ tons/sq. in.

$k_1\sqrt{r} + \int_0^r \sqrt{(r-e)}dk = 28{\cdot}46$ tons/sq. in.

$\bar{k}_P = 40{\cdot}5$ tons/sq. in.

In general, it is only necessary to calculate the mean yield stress from equations (13) or (17) for passes on annealed materials. Unless the first pass is taken at a very light reduction, the yield stress of most commercially rolled materials increases linearly, to a first approximation, in subsequent passes. On substituting a linear relationship between $k$ and $e$ into equation (17), it will be found that $\bar{k}_P$ is equal to the yield stress of the material after strain hardening by the equivalent of 60% of this reduction in the pass. Alternatively, a mean reduction $\bar{r}_P$ may be calculated from the equation :

$$\bar{r}_P = 0{\cdot}4r_1 + 0{\cdot}6r_2 \quad \ldots\ldots\ldots\ldots\ldots\ldots(18)$$

and the mean yield stress read off from the yield-stress/strain curve at that reduction.

## EQUATION TO SPECIFIC ROLL TORQUE

### Equation for $G_0/\bar{k}_G H^2$

The equation to the roll torque given in equation (9) is equivalent to :

$$\frac{G_0}{\bar{k}_G H^2} = \frac{a^2}{\mu^2} f_G(a, r) \quad \ldots\ldots\ldots\ldots\ldots\ldots(19)$$

and the quantity $G_0/\bar{k}_G H^2$ may be expressed as a function of the variables $R/H$, $r$, $\bar{k}_G$, and $\mu$. It has been calculated for the same range in these variables as the function $P_0 r/\bar{k}_P H$ and is presented in Figs. 11–13.

Equation (19) neglects the moment of the normal pressure, $s$, about the roll axis, which may be appreciable when $R'/R$ is very large. A correction to $G_0$ may be made for this effect by means of the relation due to Hill.[17] The corrected torque $G'$ is given by :

$$G' = G_0\left[1-\left(\frac{R'}{R}-1\right)\left(\frac{\alpha P_0 R}{2G_0}-1\right)\right]$$

### Mean Yield Stress $\bar{k}_G$

The use of the mean yield stress defined by equations (13) and (17) gives rise to relatively large errors when used to calculate the torques required to roll annealed or slightly strain-hardened materials. A suitable mean yield stress may be derived from reasoning similar to that on p. 25.

The equation for the specific roll torque may also be written as

$$G_0 = RR'\int_0^\alpha s\theta d\theta$$

and the term $\int_0^\alpha s\theta d\theta$ is the moment about its ordinate of the area enclosed by the angular distribution of pressure in Fig. 10. The moment of the area $OABQ$ is $\int_0^\alpha k\theta d\theta$ and the mean yield stress $\bar{k}_G$ must provide an area of equivalent moment ; hence :

$$\int_0^\alpha \bar{k}_G\,\theta d\theta = \text{moment } OABQ = \int_0^\alpha k\,\theta d\theta$$

so that $$\bar{k}_G = \frac{2}{\alpha^2}\int_0^\alpha k\theta d\theta = \frac{1}{r}\int_0^r k de \quad \ldots\ldots\ldots\ldots(20)$$

## Table IV

### EXAMPLE OF A CALCULATION OF A PASS SCHEDULE

| Strip Thickness, in. | | $R/H$ | $\mu$ | Reduction, % | | | | | Mean Yield Stress, tons/sq. in. | | $\frac{P_0 r}{\bar{k}_P H}$ | $\frac{G_0}{\bar{k}_G H^2}$ | $P_0$, tons/in. | $G_0$, tons-in./in per roll |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Before Pass | After Pass | | | In Pass | Total Before Pass | Total After Pass | Mean Reduction | | $\bar{k}_P$ | $\bar{k}_G$ | | | | |
| | | | | | | | $\bar{r}_P$ | $\bar{r}_G$ | | | | | | |
| 0·0625 | 0·0500 | 160 | 0·08 | 20 | 0 | 20 | — | — | 30·9 | 28·0 | 1·81 | 21·4 | 17·6 | 2·34 |
| 0·0500 | 0·0400 | 200 | | 20 | 20 | 36 | 29 | 28 | 39·8 | 39·2 | 2·55 | 28·9 | 25·0 | 2·82 |
| 0·0400 | 0·0320 | 250 | | 20 | 36 | 51 | 45 | 44 | 44·3 | 44·1 | 3·64 | 39·0 | 32·3 | 2·75 |

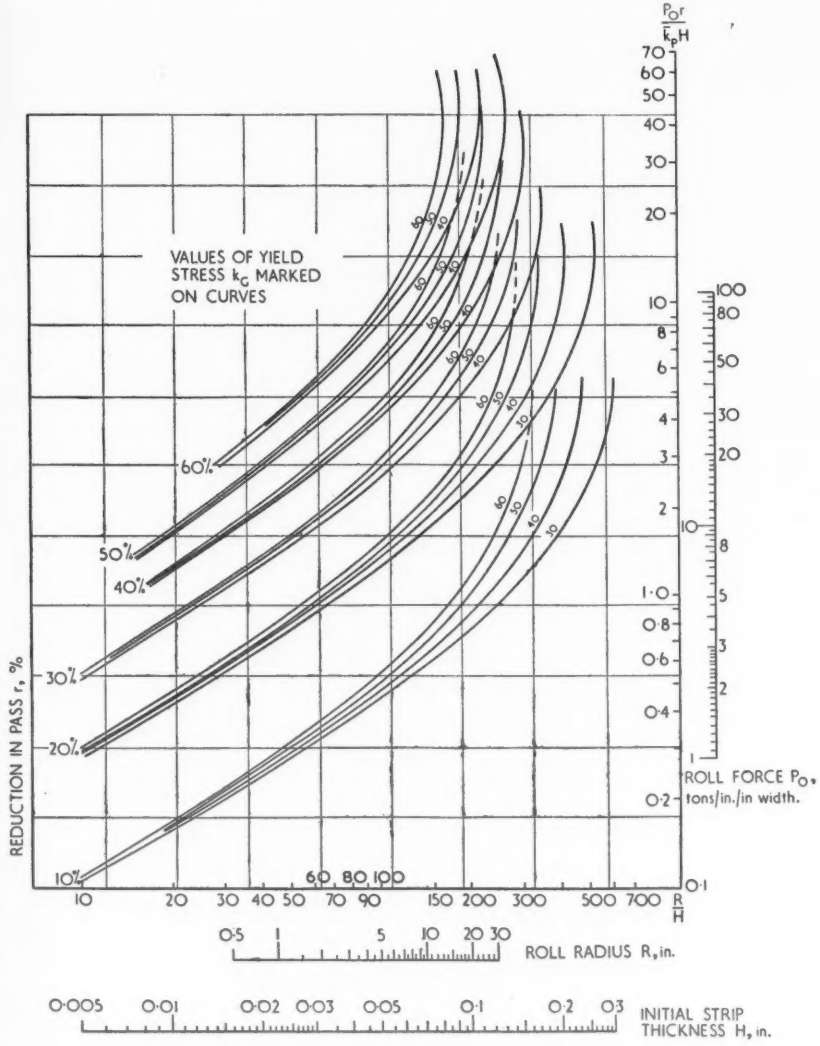
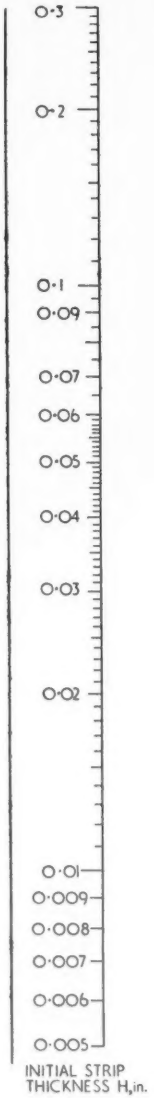
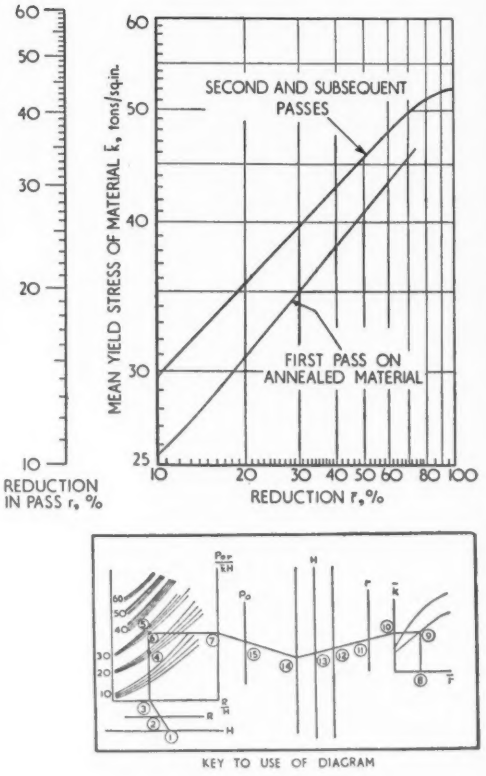



**Fig. 14—Roll force per in. width for rimming steel ($\mu = 0.08$)**




Note: For first passes the mean yield stress of the material is read off against the reduction in the pass, but a mean reduction $\bar{r}$ is used to determine the mean yield stress for second and subsequent passes


SECOND AND SUBSEQUENT PASSES
FIRST PASS ON ANNEALED MATERIAL
MEAN YIELD STRESS OF MATERIAL k, tons/sq.in.
REDUCTION IN PASS r, %
REDUCTION r, %
KEY TO USE OF DIAGRAM

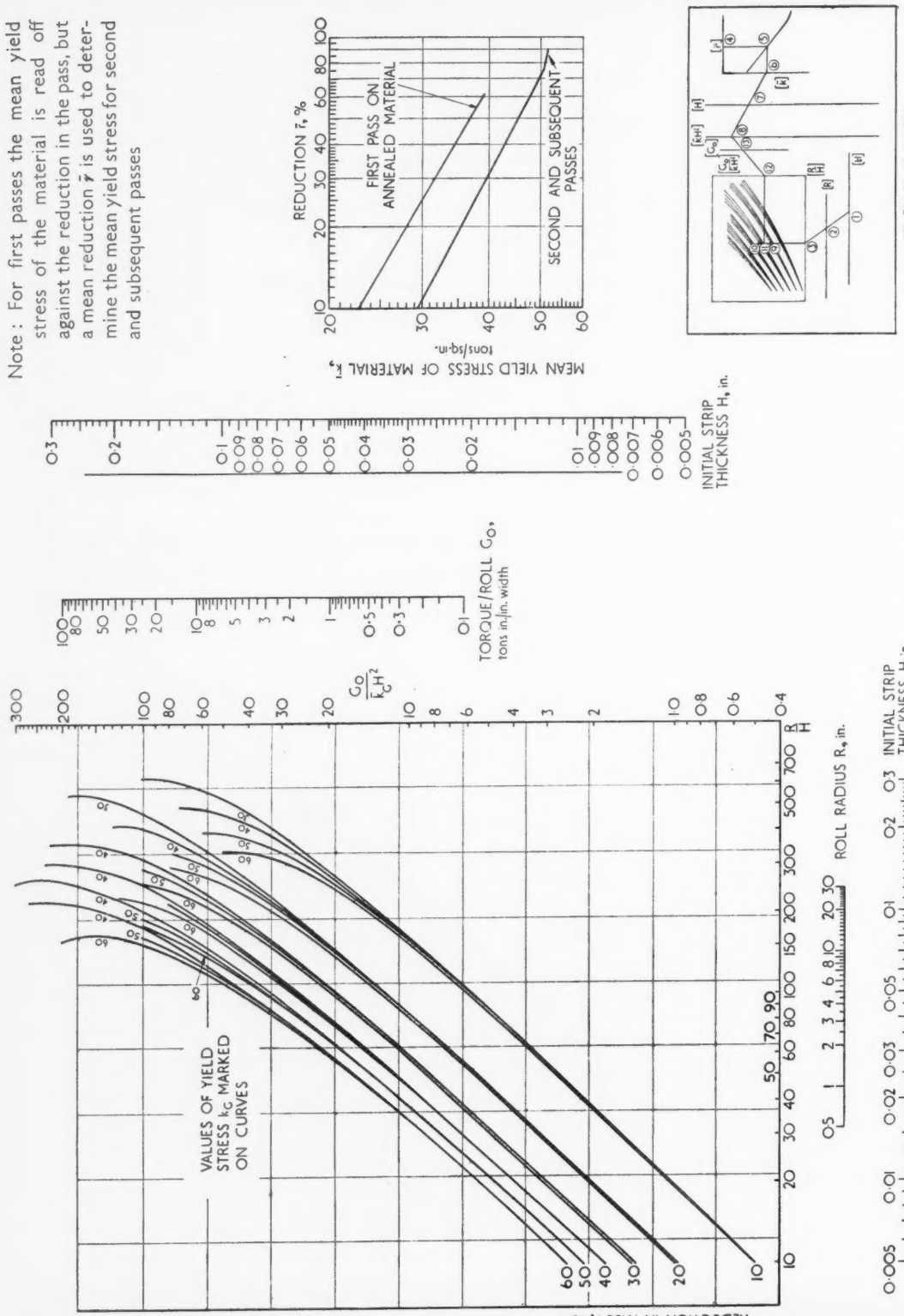

Note: For first passes the mean yield stress of the material is read off against the reduction in the pass, but a mean reduction $\bar{r}$ is used to determine the mean yield stress for second and subsequent passes
MEAN YIELD STRESS OF MATERIAL $\bar{k}_c$, tons/sq.in.
REDUCTION r, %
FIRST PASS ON ANNEALED MATERIAL
SECOND AND SUBSEQUENT PASSES
KEY TO USE OF DIAGRAM
INITIAL STRIP THICKNESS H, in.
TORQUE/ROLL $G_o$, tons in./in. width
$\frac{G_o}{k_c H^2}$
$\frac{R}{H}$
ROLL RADIUS R, in.
INITIAL STRIP THICKNESS H, in.
VALUES OF YIELD STRESS $k_c$ MARKED ON CURVES
REDUCTION IN PASS r, %

**Fig. 15—Torque per roll per in. width of strip mild steel ($\mu = 0{\cdot}08$)**

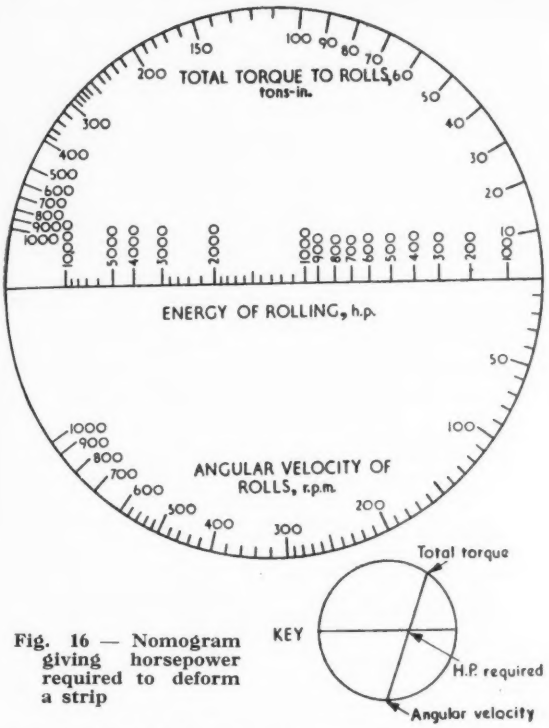



**Fig. 16 — Nomogram giving horsepower required to deform a strip**

An example of the calculation is given in Table III, where total of last column =

$$\int_0^r kde = 17{\cdot}68 \text{ tons/sq. in.}$$

$$\bar{k}_G = 35{\cdot}4 \text{ tons/sq. in.}$$

The mean yield stress $\bar{k}_G$ is the average value of the yield stress over the range of reductions in the pass. When calculating passes on strain-hardened materials, the yield stress at the reduction

$$\bar{r}_G = \tfrac{1}{2}(r_1 + r_2) \quad \ldots\ldots (21)$$

may be used without great error in place of $\bar{k}_G$ calculated from equation (20).

## CALCULATION OF ROLL FORCE AND TORQUE

### From Figs. 7–9 and 11–13

The data required for a solution are the work-roll-radius/entry-strip-thickness ratio ($R/H$), the coefficient of strip friction, the pass reductions, and the mean yield stress of the material in the pass which may be derived either from equations (17) and (20) or the approximation to them given in equations (18) and (21). The value of $P_0 r/\bar{k}_P H$ and $G_0/\bar{k}_G H^2$ may be found from the graphs by interpolating for the yield stress and pass reduction. The specific roll force may be obtained by multiplying the former quantity by $\bar{k}_P H/r$ and the latter by $\bar{k}_G H^2$. It should be remembered that in the latter calculation the specific torque *per roll* will then be obtained.

An example of a calculation of pass schedule is set out in Table IV.

### Nomographic Solution for Roll Force

A nomogram for calculating specific roll force is given in Fig. 14. It is constructed around a diagram of $P_0 r/\bar{k}_P H$ against $R/H$ for $\mu = 0{\cdot}08$, covering a range of reductions from 10% to 60% with a suitable range of yield stress. The parameter $P_0 r/\bar{k}_P H$, which has been calculated from the equations on p. 25 has been used in place of the simpler function $P_0/\bar{k}_P H$ in order to separate the families of curves for the different reductions on these nomograms.

The variables $R/H$ and $P_0 r/\bar{k}_P H$ are scaled logarithmically. The values of $R/H$ for a pass are set up from scales of roll radius $R$ and strip thickness before the

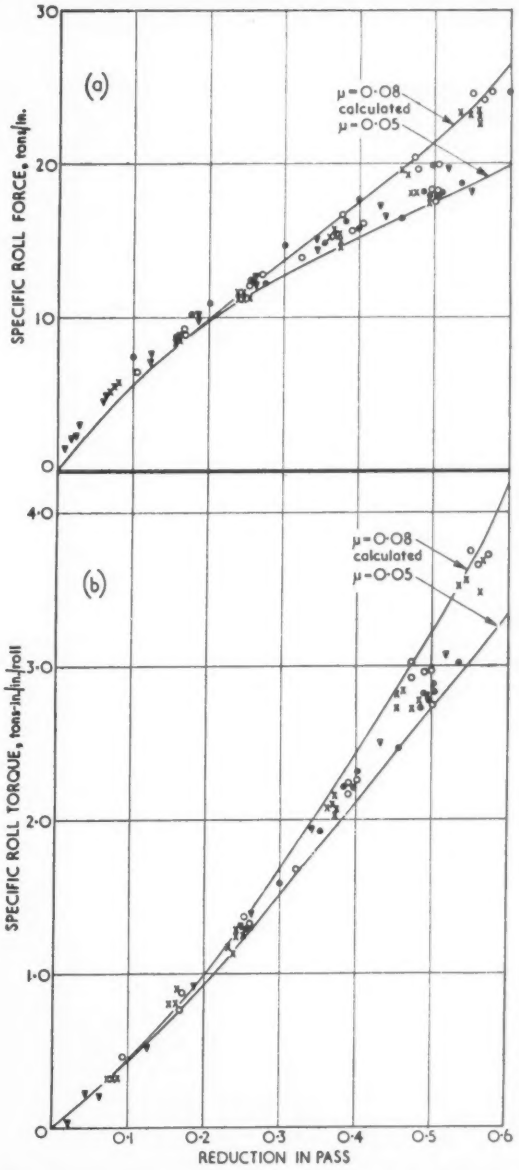



**Fig. 17—Calculated and measured values of (*a*) specific roll force, (*b*) specific roll torque for mild-steel strip, 0·063 in. thick × 3·50 in. wide**

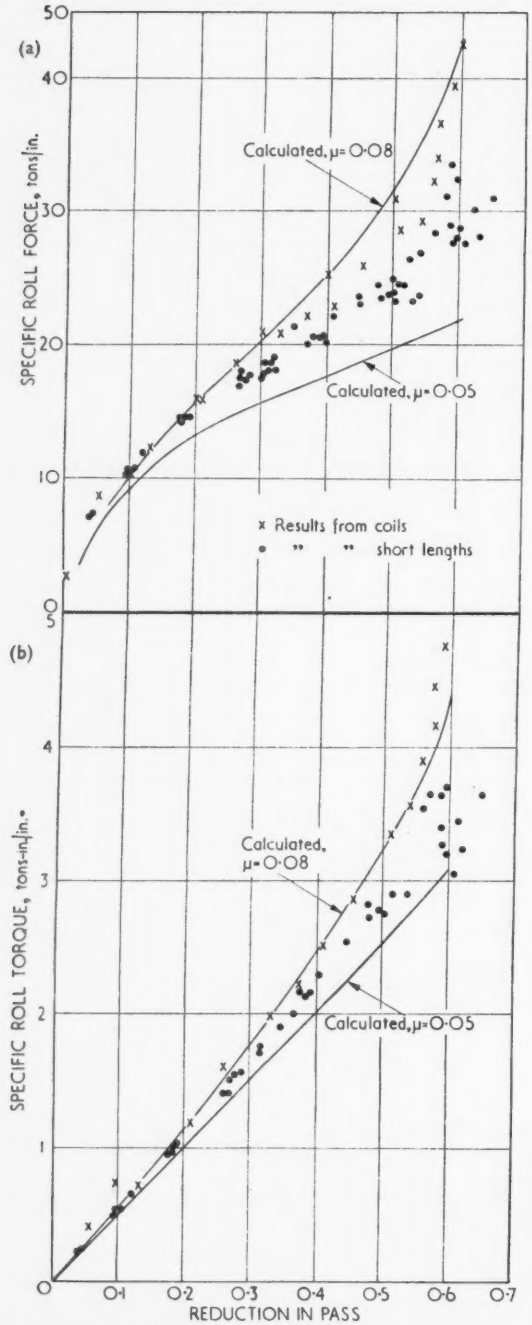



**Fig. 18—Calculated and measured values of (*a*) specific roll force, (*b*) specific roll torque for prestrained mild-steel strip, 0·038 in. thick × 3·5 in. wide**

pass $H$ on a subsidiary nomogram attached to the $R/H$ axis of the diagram. The required value of $P_0 r/\bar{k}_P H$ is then obtained by interpolating for the pass reduction and mean yield stress amongst the families of curves on the diagram. The specific roll force $P_0$ is derived from this value by means of a second set of subsidiary nomograms attached to the axis of $P_0 r/\bar{k}_P H$. The key printed on the nomogram illustrates the sequence of steps in the graphical solution.

The yield-stress/strain curve for the material is plotted on the right-hand diagram of the nomogram. The mean yield stress after the first pass is read off against the mean reduction calculated from equation (18). An example of such a calculation is given in the first eight columns of Table IV. For first passes on annealed materials, values of $\bar{k}_P$ covering a suitable range of reductions, are calculated from equation (17) and added to the yield stress diagram or obtained from data given in the companion paper.[6] As an example, the yield stress in plane compression for 0·08% C steel has been added to Fig. 14, together with the corresponding curve for $\bar{k}_P$ for the annealed material.

### Roll Torque Nomograms

The roll torque nomogram given in Fig. 15 is constructed around a diagram of $G_0/\bar{k}_G H^2$ against $R/H$ for $\mu = 0{\cdot}08$. The specific roll torque is obtained by using subsidiary nomograms attached to the axes of the diagram, in a manner similar to the roll force nomograms.

The yield stress in plane compression and the mean yield stress $\bar{k}_G$ for first passes of the material must be added, as in the roll force nomograms. In this case $\bar{k}_G$ for the second and subsequent passes is read off against the mean reduction calculated from equation (21).

The energy of rolling in horsepower units may be calculated from the total roll torque and the angular velocity of the rolls by means of the circular nomogram in Fig. 16. The *total* roll torque is obtained by multiplying the specific roll torque $G_0$ by the factor numerically equal to twice the strip width in inches.

## EXPERIMENTAL CHECK OF THE EQUATIONS

The nomograms for mild steel have been checked against measurements made in the experimental mill on coils of strip with yield-stress/strain curves very close to those taken for the nomograms. The coils were bright-annealed and initially 0·063 ± 0·001 in. thick and 3·5 ± 0·02 in. wide. During these experiments the rolls were reground twice to an average

**Table V**

**ROLL FORCE FOR LARGE PRODUCTION MILLS**

| Ref. | Ingoing Thickness, in. | Rolled Thickness, in. | Reduction in Pass, % | Total Load | |
|---|---|---|---|---|---|
| | | | | Calculated, tons | Measured, tons |
| 1*a* | 0·137 | 0·109 | 20·4 | 1010 | 1050 |
| *b* | 0·109 | 0·097 | 11·0 | 960 | 890 |
| *c* | 0·097 | 0·089 | 8·2 | 860 | 810 |
| 2*a* | 0·115 | 0·088 | 23·5 | 1020 | 1065 |
| *b* | 0·088 | 0·077 | 12·5 | 960 | 980 |
| 3*a* | 0·091 | 0·071 | 22·0 | 970 | 1085 |
| *b* | 0·071 | 0·062 | 12·7 | 910 | 960 |
| 4*a* | 0·078 | 0·064 | 17·9 | 870 | 955 |
| *b* | 0·064 | 0·056 | 12·5 | 880 | 880 |

**Table VI**
**ESTIMATION OF ROLL FORCE AND TORQUE FROM MODEL**

| Pass No. | Pass Schedule of Original, in. | Pass Schedule of Model, in. | Reduction in Pass, % | Measured* Total Roll Load in Model, tons | Specific Roll Force in Model, tons/in. | Measured* Total Torque in Model, tons/in. | Specific Torque in Model, tons-in./in. |
|---|---|---|---|---|---|---|---|
| 1 | 0·0625 | 0·0156 | 20 | 44 | 4·4 | 2·92 | 0·146 |
| 2 | 0·0500 | 0·0125 | 20 | 62·5 | 6·25 | 3·52 | 0·176 |
| 3 | 0·0400 | 0·0100 | 20 | 80·7 | 8·07 | 3·44 | 0·172 |

*These data have been obtained in this instance by the calculation shown in Table IV

**Table VII**
**ESTIMATION OF ROLL FORCE AND TORQUE FROM MODEL**

| Pass No. | Model Specific Roll Force, tons/in. | 100-in. Wide Strip | | Model Specific Torque, tons-in./in. | 100-in. Wide Strip | |
|---|---|---|---|---|---|---|
| | | Specific Roll Force, tons/in. | Total Load, tons | | Specific Torque, tons-in./in. | Total Torque, tons-in. |
| 1 | 4·4 | 17·6 | 1760 | 0·146 | 2·34 | 468 |
| 2 | 6·25 | 25·0 | 2500 | 0·176 | 2·82 | 546 |
| 3 | 8·07 | 32·3 | 3230 | 0·172 | 2·75 | 550 |

roughness of 12–18 microinches measured parallel to the axis. The strip was rolled at a speed of 40 ft./min. and lubricated with a copious supply of soluble oil emulsion in water.

Results from single passes on four annealed coils are shown in Figs. 17*a* and *b* together with curves calculated from the nomograms for $\mu = 0{\cdot}08$ and from the values for $P_0r/\bar{k}_PH$ and $G/\bar{k}_GH^2$ for $\mu = 0{\cdot}05$

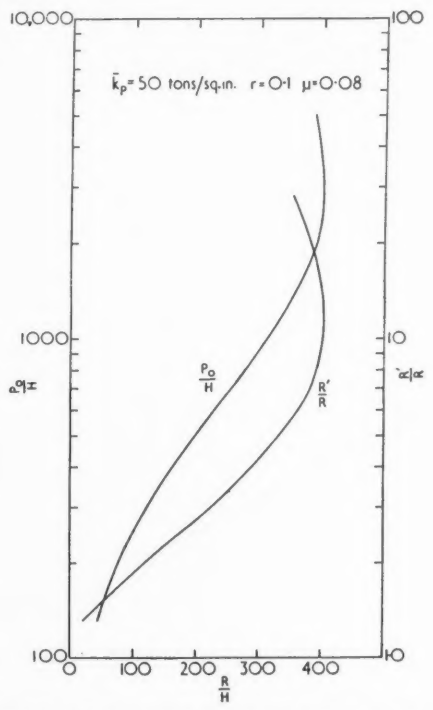



**Fig. 19—Solution of equations (10) and (12)**

shown in Figs. 7–9 and 11–13. The results from each of the coils used are denoted by different symbols on the diagrams. The measured values fall within the curves calculated for $\mu = 0{\cdot}05$ and $0{\cdot}08$ except at reductions below 20%, where the calculated curves are close together. Below reductions of 15% the measured values of the roll force are slightly greater than calculated, partly owing to the effect of elastic recovery of the strip and partly to errors in the measuring equipment. In these experiments no method was discovered of obtaining closer reproducibility in the results. The scatter cannot be accounted for except by assuming that the frictional conditions changed in the arc of contact between the rolls and the material. Coils prestrained by a 40% reduction and 3-ft. lengths of strip cut from the coils before rolling were used to obtain the results shown in Figs. 18*a* and *b*. There is scatter in the measurements which is also attributable to varying frictional conditions in the roll gap. The measurements made with the material in coil form agree with a value for a coefficient of friction between $0{\cdot}07$ and $0{\cdot}08$, whilst for short lengths the results agree with calculations based on an average value of $\mu = 0{\cdot}06$.

These experiments were made on a small mill with narrow strip. To assess the accuracy of the method when applied to large production mills, sheets of mild steel 48 in. wide × 72 in. long were rolled in a 4-high mill, with 20·5-in. dia. work rolls, equipped with two roll-force meters each of 1000 tons maximum load. Soluble oil was used as lubricant and the calculations were made with nomograms for $\mu = 0{\cdot}08$. The yield-stress/plane-compression curve was not measured for the material used in this experiment. The results are given in Table V. The maximum error between the calculated and experimental values is 10·6% and the average error −2·4%, which is considered reasonable in view of the experimental difficulties involved in making accurate measurements of the average thickness on sheets of this size, and the fact that the yield-stress/strain curve and frictional

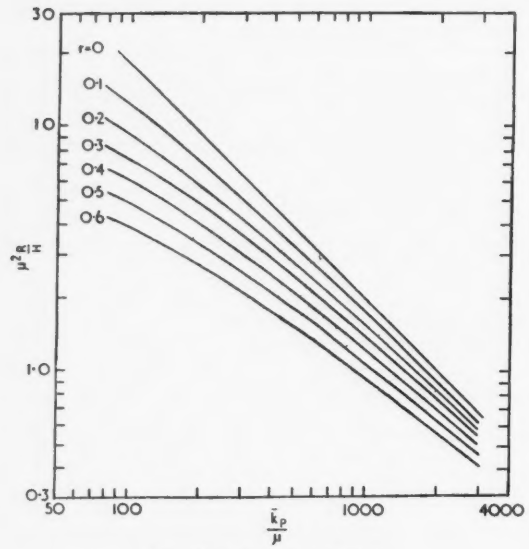



**Fig. 20—General solution**

conditions may have differed slightly from that used in designing the nomograms.

## EXPERIMENTAL DETERMINATION OF ROLL FORCE AND TORQUE

Equations (10)–(19) indicate that for a given material and a constant coefficient of friction the quantities $P_0/H$ and $G_0/H^2$ depend only on the parameter $R/H$ and the reduction in the pass. A mill fitted with roll-force and torque meters may be arranged as a model of a mill for which an estimate of the roll force and torque is required. The method of calculation is best explained by an example.

Suppose that the total load and torque are required in a proposed 4-high 20 in. and 58 in. × 110 in. mill rolling 0·08% C rimming steel initially 0·0625 in. thick and 100 in. wide, and that a mill with 5-in. dia. rolls, equipped with roll-force and torque meters, is available together with some strips of the steel 10 in. wide. It must be assumed that the lubricating conditions in the model mill are the same as those for the original 100-in. mill.

For the first pass on the 100-in. strip, the parameter $R/H$ has a value of 160 and the thickness of the strip for the model must be adjusted to give the same value of $R/H$, and so the experiment is made on annealed strip initially 0·0156 in. thick and the same pass reduction is taken. The subsequent passes are treated in a similar manner. The calculation is arranged as shown in Table VI. The torque measured in the experimental mill should be corrected for bearing losses.

Since the ratio $R/H$, the yield stress of the material, and the reductions for both mills are the same, the values of $P_0/H$ and $G_0/H^2$ for the strip 100 in. wide are equal to those for the experimental material and as one strip is four times the thickness of the other :

$P_0$ (for 100-in. wide strip) $= 4P_0$ (measured in model),
$G_0$ (for 100-in. wide strip) $= 16G_0$ (measured in model).

The calculation may then be completed as shown in Table VII.

After allowance has been made for the torque required to overcome the friction in the bearings and the losses in the drive, the power of the mill motor may be found from the circular nomogram in Fig. 16.

## MINIMUM THICKNESS IN COLD-ROLLING

It is well known to sheet rollers that there is a limit to the reduction which can be taken in a single pass on thin materials. For this reason it is usual to pack-roll the last passes when rolling to tinplate gauges on single-stand 2-high mills. Hill and Longman[18] and Stone[19] have shown that the existence of a minimum thickness in rolling follows from the use of Hitchcock's formula for roll flattening, and an estimate of the greatest reduction which may be taken with a given material and mill may be obtained from equations (10)–(12).

Figure 19 shows the solution of equations (10) and (12) for $P_0/H$ and $R'/R$ in terms of $R/H$, given that $\bar{k}_P = 50$, $r = 10\%$, and $\mu = 0{\cdot}08$. There is no value of the solution for values of the parameter $R/H$ exceeding 406 and for every value of $R/H$ less than 406 there exist two values of $P_0/H$ and $R'/R$, the lower in each being the one normally encountered in rolling, although the upper has been measured under exceptional rolling conditions. The same characteristic is shown on the curves given in Figs. 7–9. From the maximum value of $R/H$ obtained for a given set of rolling conditions the minimum entry thickness of the material may be calculated for a given mill and rolling schedule.

The general solution is conveniently presented in terms of the variables $\mu^2 R/H$ and $\bar{k}_P/\mu$ (Fig. 20). In practice the data of this diagram will be used chiefly to calculate the maximum reduction possible on a

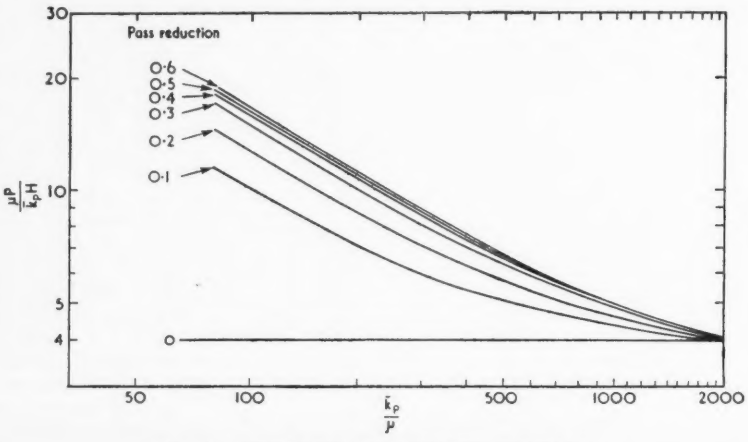



**Fig. 21—Specific roll loads at given reductions**

given material, which may be done by calculating $\mu^2R/H$ and $\bar{k}_P/\mu$ and reading off the pass reduction from the curves at the point of intersection of these co-ordinates. The specific roll load at the maximum reduction may be obtained from the parameter $P_0/\bar{k}_PH$, shown in Fig. 21 as a function of $\bar{k}_P/\mu$.

To check the calculated value of minimum thickness against experiment, a coil of annealed mild-steel strip was rolled down from a thickness 0·063 in. to 0·0113 ± 0·0002 in. using automatic gauge control. Lines were scribed on the strip 10 in. apart to form reference lengths and the coils were rolled with a copious supply of soluble oil in water as a lubricant and coolant.

After each reference length had been rolled, the load on the rolls was increased until the maximum load in the mill was reached. The first coil was rolled without tensions and subsequent coils were rolled at a constant forward tension stress of 5·6 and 14·3 tons/sq. in. The short lengths of strip were also rolled, each piece being about 5 ft. long and carrying a 10-in. reference length. After rolling, the reference lengths were measured for width and thickness, and the pass reduction was calculated assuming constant volume for the material.

The experimental results are shown in Fig. 22 and the calculated maximum reductions possible at the various tensions on this material in the experimental mill are shown in Fig. 23. The maximum reduction is clearly very sensitive to the value of the coefficient of friction between the rolls and the strip. The values of $\mu$ consistent with the minimum thickness found for coils are 0·073, 0·071, and 0·074 for $t_f$ = 0, 5·6, and 14·3 tons/sq. in., respectively, whilst the

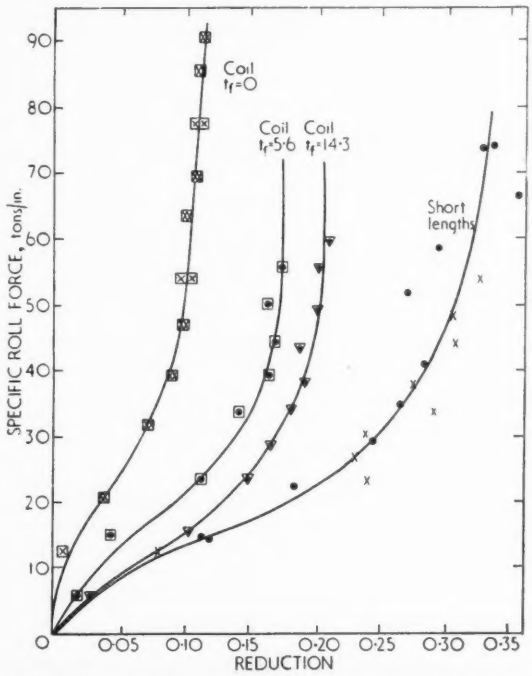



**Fig. 22—Experimental values of specific roll force**

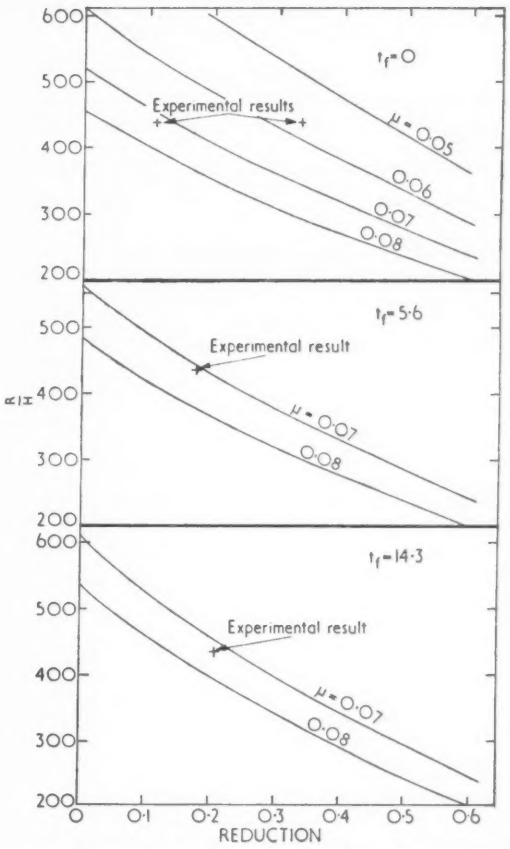



**Fig. 23—Calculated maximum reductions at differing tensions**

value of $\mu$ consistent with the maximum reduction possible on the short lengths is $\mu$ = 0·056—values close to those found in the experiments shown in Figs. 17*a* and *b*. The experiments may be considered, therefore, to be in reasonable agreement with calculation.

It was not possible to obtain experimentally the larger of the two values of the roll force predicted by the theory. As the maximum reduction was approached the experimental scatter increased and no subsequent decrease in the reduction with increasing roll load was consistently observed.

This solution of the minimum thickness to which a given material may be rolled raises a point of practical importance in rolling to light gauges, such as tinplate. In modern tandem mills, mild steel may be rolled from about 0·012 in. to 0·009 in. in the last pass between the rolls averaging 20 in. dia., and after rolling from the hot-rolled band the mean yield stress of the material in plane compression is about 50 tons/sq. in. Table VIII(*a*) shows the limiting values of $R/H$ for various coefficients of friction for this reduction.

In the tandem mill described $R/H$ = 833, and so the reduction would not be possible until the coefficient of friction fell below 0·037, a value which is possible only at relatively high rolling speeds. The

**Table VIII**

**LIMITING VALUES OF $R/H$**

| $\mu$ | 0·08 | 0·07 | 0·06 | 0·05 | 0·04 | 0·03 |
|---|---|---|---|---|---|---|
| (*a*) $H = 0{\cdot}012$ in.; $k_P = 50$ tons/sq. in.; $r = 25\%$; $t_f = t_b = 0$ | | | | | | |
| $R/H$ | 330 | 390 | 460 | 570 | 760 | 1010 |
| (*b*) $H = 0{\cdot}012$ in.; $\bar{k}_P = 50$ tons/sq. in.; $r = 25\%$; $t_b = 25$ tons/sq. in.; $t_f = 0$ | | | | | | |
| $R/H$ | 415 | 490 | 590 | 730 | 940 | 1300 |

strip must therefore be rolled with applied tensions. At the condition of minimum thickness the neutral plane will be, to a first approximation, midway between the planes of exit and entry. Therefore the mean yield stress may be written quite roughly as :

$$k' = \bar{k}_P - \tfrac{1}{2}(t_f + t_b) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (22)$$

When the interstand tension between the last two stands of the tandem is 25 tons/sq. in. the limiting values of $R/H$ to give 25% reduction for various coefficients of friction are as given in Table VIII(*b*).

With the material entering the last stand of the tandem at 0·012 in. thickness, the reduction is possible for $\mu = 0{\cdot}045$, a value which may be reached at quite low speeds with adequate lubrication and smooth rolls.

### Acknowledgments

The author is indebted to his colleagues for much of the experimental work, which was carried out during the period 1948–1952 when he was Head of the B.I.S.R.A. Rolling Mill Laboratories. In particular, the work of Mr. G. Ramsden, B.Sc., in leading the experimental team, of Mr. P. L. Barnes, who carried out the experiments on maximum reduction, and of Mr. D. F. Arthur, B.Sc., for measuring the elastic deformations in mill rolls, is acknowledged and appreciated.

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# Accelerated Strain Ageing of Mild Steel

*By B. B. Hundy, B.Sc., Ph.D., A.I.M.*

SYNOPSIS

A relation is developed connecting the time of strain ageing at room temperature with the time corresponding to the same degree of ageing at an elevated temperature. The relation is:

$$\log_{10}\frac{t_r}{t} = 4400\left(\frac{1}{T_r} - \frac{1}{T}\right) - \log_{10}\frac{T}{T_r}$$

where $t_r$ is the ageing time at room temperature $T_r$ and $t$ is the time at an elevated temperature $T$, the temperature being expressed in °K.

Experimental work on a mild rimming steel is described which shows that the relation holds for ageing temperatures up to 200° C., and further confirmation is provided by other published data.

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When mild-steel sheet is formed into a pressing it may show the defects known as Lüders lines or stretcher strains, which spoil the appearance of the pressing and often cause it to be scrapped. The tendency for this defect to occur is intimately connected with the discontinuous yield point of mild steel (Fig. 1*a*), and it is necessary to remove this yield point in some way before the steel is pressed. This is usually done at the steelworks by rolling the sheet slightly (temper rolling) so that it has a stress/strain curve of the form shown in Fig. 1*b*. It often happens, however, that the sheet is not pressed immediately it reaches the press shop, but is kept in store for a time, and it is found that the yield point (and hence the tendency to show stretcher-strain markings) gradually returns during this storage period (Fig. 1*c*). Thus it is often necessary to remove the yield point once again ; this is usually done at the press shops by putting the sheet through a roller leveller. The

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return of the yield point on storage may take between one day and several months, depending on the type of steel, the mechanical treatment, and the temperature at which it is stored.

For practical reasons, it is obviously desirable to have a rapid test which would determine the liability of a steel to form stretcher strains on ageing. Several tests have been developed empirically, but up to the present no attempt has been made to correlate them. It is the purpose of this paper to show that there is a simple relation between the time of ageing at room temperature and the time of ageing at elevated temperatures. Thus, by ageing for a short time at an elevated temperature and then testing, it is possible to predict the pressing behaviour of a steel after several months' ageing at room temperature. The theoretical relation is developed from the dislocation theory of strain ageing and is confirmed experimentally for different ageing criteria and a variety of mild steels.

## REVIEW OF PRESENT TESTS

Most of the strain-ageing tests used at present in the industry were developed for testing stabilized steels, *i.e.*, steels treated with aluminium or vanadium to prevent the phenomenon of strain ageing. These tests have only to show whether the steelmaking practice and annealing treatments were correct or not, *i.e.*, whether the steel is ' ageing ' or ' non-ageing.' The usual test is one that has been described by Low and Gensamer[1] and by others.[2] A test piece is strained 10% in tension, aged at 100° or 200° C., and then retested to measure the increase in strength on ageing. If the increase in strength is less than 5% the steel is essentially non-ageing. Another test[3] is to compare the appearance of the stress/strain curves and the ultimate tensile strengths from tests at room temperature and 200° C. A correctly stabilized steel has a smooth stress/strain curve and a lower strength at 200° C. than at room temperature, whereas a non-stabilized steel shows the well-known phenomenon of blue brittleness at the higher temperature.

These tests, however, cannot predict the ageing behaviour of a normal rimming steel which ages very rapidly. The rate of return of the yield-point depends on the temper-rolling conditions, so that the sheet must be tested in the tempered condition. It would be helpful to the steelmaker if he had a rapid test that would show whether the temper-rolling treatment had been correct or not, and a test that has sometimes been used for this is to age the temper-rolled steel for a given time at an elevated temperature and then determine its probable behaviour during subsequent pressing from the length of the yield-point elongation in a tensile test. At present, however, the correlation between ageing times at room temperature and at elevated temperatures is rather uncertain, and this test is not in general use.

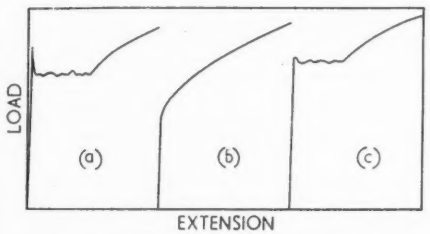


**Fig. 1—Effect of working and ageing on the stress/strain curve of mild steel: (*a*) Annealed; (*b*) rolled or severely roller-levelled; (*c*) rolled and aged**

## DISLOCATION THEORY AND ACCELERATED STRAIN AGEING

The Cottrell–Bilby theory of strain ageing[4] makes it possible to develop an expression connecting strain ageing at room temperature and elevated temperatures, and for that reason some space is given to a brief recapitulation of the essentials of the theory.

According to this theory, the yield-point phenomenon in steel is caused by a segregation of carbon and/or nitrogen atoms to the many dislocations present in the iron lattice. These solute atoms tend to relieve the stresses around the dislocations, and from energy considerations it is possible to show that a higher stress is needed to cause plastic flow (*i.e.*, movement of dislocations) under these conditions than when the solute atoms are scattered at random through the lattice. Thus, the upper yield point is the stress needed to tear these dislocations away from their surrounding ' atmospheres ' of carbon and nitrogen atoms. Once the dislocations have been torn away, the force needed to keep them moving is not so high and the stress falls to the lower yield point. Strain ageing is the result of the carbon and/or nitrogen atoms diffusing through the lattice of the strained iron to the new positions of the dislocations, locking them in place as before. The extent of strain ageing at a certain time after straining will be dependent on the rate of diffusion of the carbon (or nitrogen) atoms, on the number of atoms in solution, on the temperature, and on the time.

Expressions have been developed which connect these various factors and in the Appendix they are used to derive the following equations relating the time of strain ageing at room temperature to that at higher temperatures :

$$\log_{10}\frac{t_r}{t} = 4400\left(\frac{1}{T_r}-\frac{1}{T}\right) - \log_{10}\frac{T}{T_r},$$

assuming that carbon causes strain ageing, and

$$\log_{10}\frac{t_r}{t} = 4000\left(\frac{1}{T_r}-\frac{1}{T}\right) - \log_{10}\frac{T}{T_r},$$

assuming that nitrogen causes strain ageing, where $t_r$ is the strain-ageing time at room temperature $T_r$, and $t$ is the time giving a similar degree of ageing at an elevated temperature $T$, the temperatures being expressed in ° K.

It will be seen that these two equations are very similar and in general they will not be discussed separately.

## EXPERIMENTS ON ACCELERATED STRAIN AGEING

A number of strain-ageing tests were made at ageing temperatures ranging from 15° to 240° C. so as to obtain data on the relationship between ageing at the various temperatures. Most of the work was concerned with steel that had been temper-rolled 4% ; this temper is rather higher than is normally used in

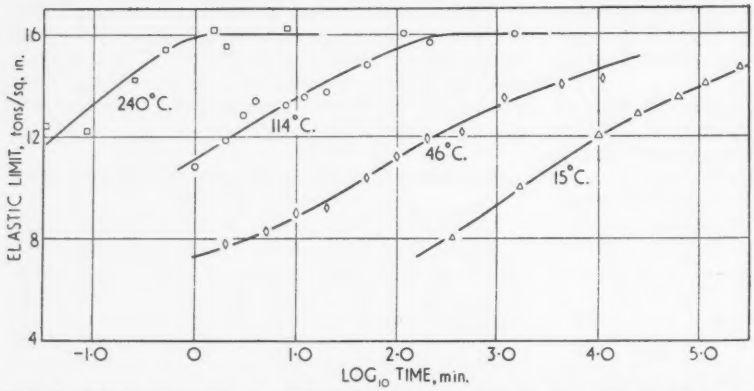


**Fig. 2—Effect of ageing at different temperatures on the elastic limit of temper-rolled mild steel**

industry, but it was chosen because it delayed the return of the yield point for a longer time than lower reductions. Other samples were strained 5% in tension, so as to pull the steel through the yield-point elongation. A yield point returned in about 3 days at room temperature for these specimens, compared with 3 months for the temper-rolled samples.

The progress of the ageing was followed by determining the stress/strain curves after various ageing times. The following mechanical properties were used as criteria :

(i) Proportional limit
(ii) Yield-point elongation
(iii) Elongation on a 2-in. gauge length (both the uniform and the total elongations)
(iv) Ultimate tensile strength.

The material used was extra-deep-drawing-quality mild-steel sheet supplied in the annealed condition. The chemical analysis of the steel was : C, 0·056% ; Mn, 0·30% ; S, 0·032% ; P, 0·016% ; Sn, 0·037% ; Cu, 0·16% ; Ni, 0·07% ; N, 0·0044%. Microscopic examination showed that the steel had a fairly uniform grain size of about A.S.T.M. 7 and was reasonably free from inclusions. Temper rolling was carried out on a 10 in. × 10 in. experimental mill with a rolling speed of 50 ft./min. To minimize any extraneous ageing effects after rolling or stretching and before ageing at a particular temperature, the specimens were kept cold in a box with dry ice, except for about 20 min. when the tensile specimens were being prepared. Ageing was carried out at room temperature (15° C.) and in oil baths at 46°, 58·5°, 114°, and 240° C. After ageing, the stress/strain curves were determined at room temperature using a Hounsfield tensometer and a Lindley extensometer.

Figure 2 shows the rise in the elastic limit with time for specimens temper-rolled 4% and aged at different temperatures. Similar curves were obtained for the other mechanical properties studied and from these curves the function $\log_{10}(t_r/t)$ was determined for the various ageing temperatures, at different stages in the ageing process. The values of this function at the different temperatures, together with the theoretical values from the equations, are given in Table I. This table is given so that an estimate can be made of the reliability of the theoretical values for the two different modes of deformation and for the different criteria (U.T.S., elongation, etc.) used to follow the ageing process.

There is reasonable agreement between the predicted and measured values of the ageing-time ratios for ageing temperatures up to 114° C., but the values for ageing at 240° C. are lower than those predicted. At this temperature, ageing was complete in 1–2 min. ; the specimens used, however, took about 10 sec. to reach the temperature of the bath, and so the times of ageing are seriously overestimated. It is thought, however, that the agreement between predicted and measured values for the other ageing temperatures is as close as can be reasonably expected. The average values from Table I are plotted in Fig. 3*a*, together with the theoretical curves, taking the room temperature to be 15° C.

## EXPERIMENTAL RESULTS OF OTHER WORKERS

Data published by other workers give further experimental confirmation of the theoretical relationship.

**Table I**

**COMPARISON OF AGEING TIMES AT ROOM (15° C.) AND ELEVATED TEMPERATURES**

| Treatment before Ageing | Ageing Temperature, °C. | $\log_{10}\frac{t_r}{t}$ | | | | | |
|---|---|---|---|---|---|---|---|
| | | Theoretical* | Elastic Limit† | Yield Point Elongation† | Total Elongation on 2 in.† | Uniform Elongation† | U.T.S.† |
| Temper-rolled 4% | 46 | 1·25, 1·45 | 1·65, 1·6, 1·6, 1·35 | 1·3, 1·65 | 1·3, 1·2, 1·15, 1·1 | 1·4, 1·4, 1·3 | 1·4, 1·35 |
| | 114 | 3·4, 3·75 | 4·0, 3·8, 3·75, 3·55 | 4·0, 3·9 | 3·7, 3·5, 3·35, 3·35 | 3·6, 3·4, | 3·4, 3·4 |
| | 240 | 6·1, 6·7 | 5·85, 5·5, 5·4, 5·4 | 5·9, 5·6 | 6·0, 5·8, 5·8, 5·35 | 5·5, 5·4, 5·4 | 5·4, 5·3 |
| Strained 5% in tension | 58·5 | 1·7, 1·95 | 2·1, 1·8, 1·7, 1·6 | 2·0, 1·75, 1·75 | 1·75, 1·75, 1·7 | 1·8 | 1·4 |

*The first figures in this column are calculated assuming the diffusion coefficient for nitrogen and the second are for carbon diffusion.
†The figures given in these columns are for different levels of ageing.

Davenport and Bain[5] used the Rockwell hardness test as a measure of strain ageing in a basic open-hearth rimming steel. Figure 3*b* shows their results for both freshly quenched and quench-aged material in terms of $\log_{10}(t_r/t)$ for ageing temperatures of 40°, 80°, 100°, and 150° C., together with the predicted curve for a room temperature of 20° C.

Kenyon and Burns[6] determined a series of autographic stress/strain curves for a mild steel cold-rolled 1% and aged for varying times at room temperature, 100°, and 205° C. From these curves it is possible to estimate the times at the various ageing temperatures which lead to the same yield-point elongation, and again in Fig. 3*b* these are plotted as the function $\log_{10}(t_r/t)$.

In a paper on accelerated strain ageing, Shoenberger and Paliwoda[7] present curves connecting ageing times at elevated temperatures with ageing at room temperature. They used the Rockwell hardness test as a criterion of ageing and the tests were carried out on steel heated in a gradient furnace, so that different positions along the strip corresponded to different ageing temperatures. Points taken from their curves are also shown in Fig. 3*b*.

Similar values of the function $\log_{10}(t_r/t)$ are also given in Fig. 3*b*, using the increase in U.T.S., the decrease in impact toughness, and the decrease in electrical resistance as criteria of strain ageing. These figures were obtained from the work of Köckritz,[8] Osborn,[9] and Cottrell and Churchman,[10] respectively.

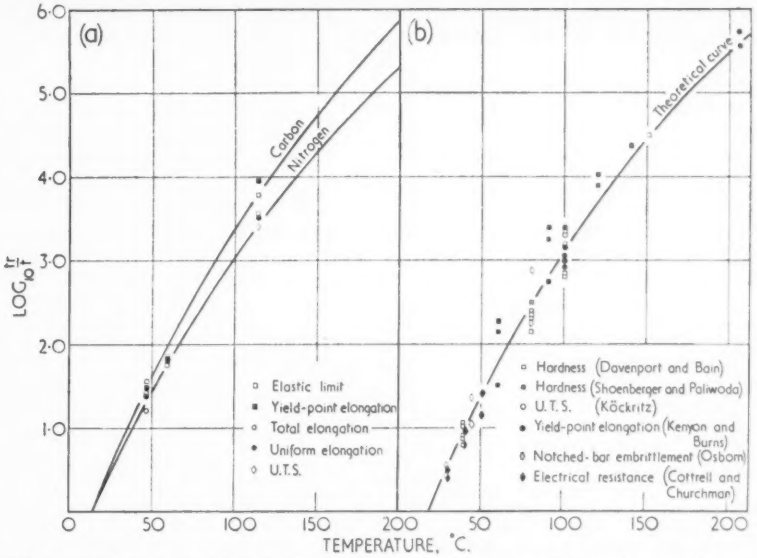


**Fig. 3—Variation of ageing time with temperature. Room temperature: (*a*) 15° C.; (*b*) 20° C.**

## CONCLUSIONS

The results presented in this paper, using a number of different criteria of strain ageing, show that the times of ageing at room and elevated temperatures can be correlated by means of the equation :

$$\log_{10}\frac{t_r}{t} = 4400\left(\frac{1}{T_r} - \frac{1}{T}\right) - \log_{10}\frac{T}{T_r}.$$

The sheet-steel industry at present favours an ageing temperature of 100° C., and there seem to be good reasons for the choice of this temperature : ageing is fast enough not to delay routine tests unduly but is not so rapid as to make small variations in the time of ageing important ; also it is not necessary to use a special oven for ageing, since boiling water can be used instead. The comparable times of ageing at this temperature, 15°, and 21° C. are given in Table II. Sometimes, however, when the speed of testing is of paramount importance, it is necessary to use a higher ageing temperature and Table II also gives the comparable times for ageing at 120° and 150° C.

### Table II

**EQUIVALENT AGEING TIMES AT ROOM TEMPERATURE AND AT ELEVATED TEMPERATURES**

| 15° C. | 21° C. | 100° C. | 120° C. | 150° C. |
|---|---|---|---|---|
| 1 year | 6 months | 4 hr. | 1 hr. | 10 min. |
| 6 months | 3 months | 2 hr. | 30 min. | 5 min. |
| 3 months | 6 weeks | 1 hr. | 15 min. | 2½ min. |
| 1 month | 2 weeks | 20 min. | 5 min. | |
| 1 week | 4 days | 5 min. | | |
| 3 days | 36 hr. | 2 min. | | |

The figures given in Table II are in rough agreement with the empirical values used in the sheet-steel industry. Jevons,[11] for example, quotes 3 hr. at 100° C. as being equivalent to 6 months at room temperature. It is therefore suggested that, unless there is any need for a very rapid test, 1 hr. at 100° C. might be a suitable accelerated strain-ageing test. This is equivalent to ageing at 15° C. for 3 months or at 21° C. for 6 weeks. Temper-rolled sheet is not normally stored as long as this, so that a tensile test after this accelerated ageing treatment should show whether troubles due to stretcher straining during pressing will arise or not.

Table II also shows that an increase of the room temperature from 15° to 21° C. doubles the rate of ageing. This, of course, explains the usual outbreak of stretcher strains in pressings during warm summer weather and suggests that the steel-sheet stores should be kept as cool as possible. A decrease in the storage temperature to 0° C. would increase the safe ageing time by a factor of 10, and it is unfortunate that it does not seem economically possible to store steel sheets in a refrigerated room, as suggested by Jevons.[11] From the figures presented in the present paper, however, it seems that it might be worthwhile investigating the possibility of improving the steel stores in press shops. By using a separate well-insulated room for the stores, with no space heating, it might be possible to store temper-rolled steel for far longer than at present without having to roller-level

the sheets before pressing. In this connection it should also be remembered that ageing reduces the ductility of sheet steel and there might perhaps be less scrap with difficult pressings if the ageing could be minimized.

### Acknowledgments

The mild steel was kindly supplied by Mr. H. Edwards of John Summers and Sons, Ltd. The author would like to thank Mr. T. D. Boxall for his help with the experimental work.

## APPENDIX

## Derivation of Equations Governing Accelerated Strain Ageing

Cottrell and Bilby[4] have shown theoretically, and Harper[12] has confirmed experimentally, that strain ageing is governed by the equation

$$n(t) = \alpha N\left(A\frac{Dt}{kT}\right)^{\frac{2}{3}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where $n(t)$ = Number of solute atoms transferred to unit length of a dislocation in a time $t$ sec. (This is a measure of the degree of ageing)
$\alpha$ = A number nearly equal to 3
$N$ = Number of solute atoms in solution in unit volume
$A$ = Parameter measuring the interaction between the dislocation and the solute atom
$D$ = Diffusion coefficient of the solute in α-iron,
$k$ = Boltzmann's constant
$T$ = Absolute temperature, ° K.

For equal degrees of strain ageing at different temperatures (*e.g.*, at room temperature $T_r$ and some other temperature $T$) it can be said that :

$$N_r\left(A\frac{D_r t_r}{kT_r}\right)^{\frac{2}{3}} = N\left(A\frac{Dt}{kT}\right)^{\frac{2}{3}}.$$

Then, if it is assumed that $N_r = N$,

$$\frac{D_r t_r}{T_r} = \frac{Dt}{T} \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Wert[13] has shown that the diffusion coefficient of carbon in α-iron is given by

$$D_C = 0{\cdot}02e^{-20{,}100/RT} \quad \text{sq. cm./sec.} \quad \ldots\ldots\ldots(3)$$

where $R$ is the gas constant (= 1·986 cal./° C. mole), and that the diffusion coefficient for nitrogen in α-iron is given by

$$D_N = 0{\cdot}003e^{-18{,}200/RT} \quad \text{sq. cm./sec.} \quad \ldots\ldots\ldots(4)$$

Then, substituting equation (3) in equation (2),

$$\frac{e^{-20{,}100/RT_r} \times t_r}{T_r} = \frac{e^{-20{,}100/RT} \times t}{T}$$

or

$$\frac{t_r}{t} = \frac{e^{-20{,}100/RT}}{e^{-20{,}100/RT_r}} \times \frac{T_r}{T}.$$

Then

$$\log_{10}\frac{t_r}{t} = \frac{20{,}100}{R} \times \log_{10}e \times \left(\frac{1}{T_r} - \frac{1}{T}\right) - \log_{10}\frac{T}{T_r}.$$

Therefore

$$\log_{10}\frac{t_r}{t} = 4400\left(\frac{1}{T_r} - \frac{1}{T}\right) - \log_{10}\frac{T}{T_r} \quad \ldots\ldots\ldots(5)$$

This equation is modified only slightly if equation (4) is substituted for nitrogen diffusion in equation (2). Then

$$\log_{10}\frac{t_r}{t} = 4000\left(\frac{1}{T_r} - \frac{1}{T}\right) - \log_{10}\frac{T}{T_r} \quad \ldots\ldots\ldots(6)$$

Therefore, assuming that the dislocation theory of strain ageing is correct and that all strain-ageing phenomena are governed by this theory, a simple equation has been obtained, which enables the time of ageing at any temperature $T$ to be converted to the equivalent time of ageing at room temperature $T_r$. One doubtful point is whether it is justifiable to assume that the number of solute atoms in solution at room temperature is equal to the number in solution at another higher temperature. The most recent determinations[14, 15] show that the equilibrium amount of carbon in solution in iron at room temperature is about 0·0000001% and the corresponding figure for nitrogen is 0·0002%. However, if there were only these amounts of the solute atoms in solution, the steel would not show the strain-ageing phenomena.[4] It must, therefore, be assumed that the ferrite is supersaturated with carbon and nitrogen atoms; then, raising the temperature of the steel will not increase the number of carbon or nitrogen atoms in solution. Thus, provided that the ageing temperature is not too high, the assumption $N_r = N$ is justified. It is possible, however, that raising the temperature to about 200° C. may increase the number of atoms in solution ; it is therefore thought that the relation developed above will only hold up to 200° C. and it is possible that even at somewhat lower temperatures (say, 150° C.) the relation may not be exactly correct.

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# A Contribution to the Constitution of the Ternary System Fe–Mn–C

*By Kehsin Kuo and L. E. Persson*

## ISOTHERMAL SECTIONS AT 1050°, 910°, AND 690° C.

SYNOPSIS

The constitution diagrams of the ternary system Fe–Mn–C at 1050°, 910°, and 690° C. have been determined by powder-metallurgy and X-ray diffraction methods.

There is no double carbide of iron and manganese existing in this ternary system, but the solubilities of manganese in $Fe_3C$ and of iron in manganese carbides ($Mn_{23}C_6$, $Mn_7C_2$, $Mn_3C$, $Mn_5C_2$, and $Mn_7C_3$) are quite large. At 1050° C. the carbide in equilibrium with the metal phases is $(Mn.Fe)_3C$, which, extending from $Fe_3C$ to $Mn_3C$, forms a series of solid solutions. Below 1025° C. the carbide $(Mn.Fe)_{23}C_6$ also becomes stable and occurs together with $(Mn.Fe)_3C$ in equilibrium with the metal phases. Unlike the isomorphous carbide $(Cr.Fe)_7C_3$, $(Mn.Fe)_7C_3$ never appears together with any metal phase. The binary carbide $Mn_3C$ is unstable below 950° C. and the solubility of manganese in $(Mn.Fe)_3C$ decreases with decreasing temperature.

GENERALLY speaking, manganese is one of the most common alloy elements used in the steel industry, since all commercial steels contain at least 0·20–0·30% of manganese. Besides the general functions of manganese in deoxidation and in increasing the hardenability of steels, special steels with high manganese content have been manufactured, *e.g.*, Hadfield steel. The study of the equilibrium diagram of the Fe–Mn–C ternary system is therefore very important for an understanding of the constitution and properties of manganese steels.

This ternary system has previously been studied by many investigators, but the scope of study was generally limited to a restricted region of up to 1·5% of carbon and up to 17% of manganese.[1–3] Vogel and Döring[4] have published a series of constitution diagrams for the system Fe–$Fe_3C$–$Mn_3C$–Mn, and they have not noticed any manganese carbides other than α- and β-$Mn_3C$. Recently, Isobe[5] reinvestigated the binary systems Fe–Mn and Mn–C, as well as the ternary system Fe–Mn–C. In spite of the tremendous amount of work Isobe has put into these investigations, he has included only three manganese carbides in his diagrams.

One of the present authors[6] has also studied the binary system Mn–C by X-rays, and no less than five manganese carbides have been found to exist. These new findings made it desirable that the ternary system Fe–Mn–C should be re-examined. The constitution diagrams at 1050°, 910°, and 690° C. have been determined by powder-metallurgy and X-ray diffraction methods, and the results are presented here.

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### BINARY SYSTEMS

#### Fe–Mn System

This system has been thoroughly investigated earlier, and the equilibrium diagram was fairly well established. Figure 1 is taken from p. 1210 of the "Metals Handbook,"[7] based upon the published

**Table I**

**MANGANESE CARBIDES**

| Carbide | Symmetry | Lattice Constants | No. of Formula-Units per Unit Cell | Stability Range | Remarks |
|---|---|---|---|---|---|
| $Mn_{23}C_6$ | Cubic | $a = 10{\cdot}61$ Å. | 4 | Up to 1025° C. | Isomorphous with $Cr_{23}C_6$ |
| $Mn_7C_2$ | Unknown | Unknown | — | 850–1000° C. | As the structure of this carbide has not yet been determined, the formula $Mn_7C_2$ cannot be considered as certain |
| $Mn_3C$ | Orthorhombic | $a = 4{\cdot}530$ Å.<br>$b = 5{\cdot}080$ Å.<br>$c = 6{\cdot}772$ Å. | 4 | 950–1050° C. | Isomorphous with $Fe_3C$ |
| $Mn_5C_2$ | Monoclinic | $a = 5{\cdot}086$ Å.<br>$b = 4{\cdot}573$ Å.<br>$c = 11{\cdot}66$ Å.<br>$\beta = 97{\cdot}75°$ | 4 | Up to 1050° C. | — |
| $Mn_7C_3$ | Trigonal | $a = 13{\cdot}90$ Å.<br>$c = 4{\cdot}54$ Å. | 8 | Up to 1100° C. | Isomorphous with $Cr_7C_3$ |

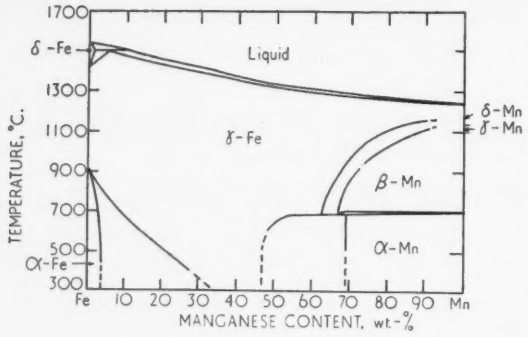



**Fig. 1—Constitution diagram of binary system Fe–Mn**

diagrams of Öhman,[8] of Gayler,[9] and of Walter and Wells.[10] Iron exists in the two allotropic forms, α-Fe (δ-Fe) and γ-Fe, and manganese exists in four allotropic forms, α-Mn, β-Mn, γ-Mn, and δ-Mn.

The crystal structure of γ-Mn has recently been discussed[11–13] and was considered to be a face-centred cubic (f.c.c.) lattice isomorphous with γ-Fe, but transformed into a face-centred tetragonal (f.c.t.) lattice on quenching to room temperature. Basinski and Christian[12] suggested that this is a martensitic reaction.

Since the ε-phase is metastable,[14] it has not been included in the equilibrium diagram.

### Mn–C System

Though the carbides of transition metals have been very extensively studied, it has hitherto not been clear what phases occur in the Mn–C system. At least five manganese carbides have been found to exist in this system[6] and their crystallographic data are shown in Table I.

Öhman, in unpublished work reported by Jacobson and Westgren,[15] has found the carbides $Mn_{23}C_6$ and $Mn_7C_3$ but not $Mn_3C$, although the presence of the latter carbide was claimed by many investigators.[4, 15] This lack of agreement is probably a result of the narrow temperature range of stability of this carbide, as shown by Fig. 2. Since the carbide $Mn_3C$ is not stable below 950° C., it can only be prepared by quenching the sample rapidly from 950–1050° C. The high-temperature form of $Mn_3C$, reported by Vogel and Döring[4] as β-$Mn_3C$, has not been confirmed.

The carbide $Mn_5C_2$ is identical with the double carbide of iron and manganese found by Öhman[16] in ferromanganese alloys. The structure of this carbide belongs to the space group $Cr^6_{2h}$–C2/c, containing 4 units of $Mn_5C_2$. However, the line intensity of the powder photograph obtained by one of the authors[6] (Table II) does not agree with that reported by Öhman.[16] A complete structure determination is still in progress.

A new carbide of manganese was found between 850° and 1000° C. with about 5·9% of carbon. The

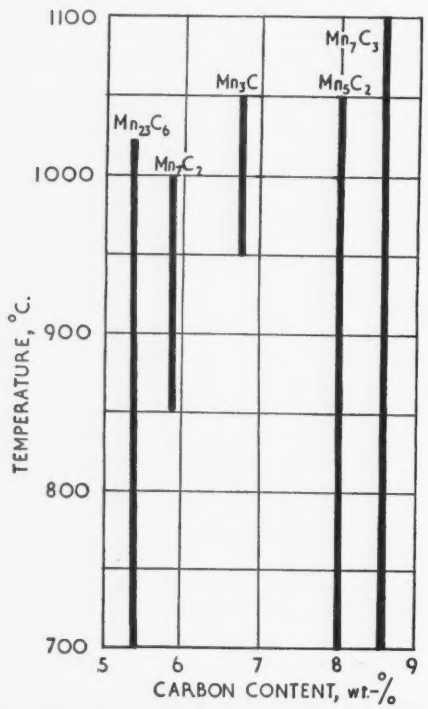



**Fig. 2—Stability range of manganese carbides[6]**

**Table II**

**X-RAY POWDER PATTERN OF CARBIDES $Mn_5C_2$ AND $Mn_7C_2$**

| $Mn_5C_2$ | | | | | $Mn_7C_2$ | |
|---|---|---|---|---|---|---|
| *h* | *k* | *l* | *I* | *d*, Å. | *I* | *d*, Å. |
| 1 | 1 | $\bar{1}$ | VW | 3·325 | W | 3·739 |
| 0 | 1 | 3 | VW | 2·938 | VW | 3·126 |
| 0 | 0 | 4 | VW | 2·881 | M | 2·519 |
| 1 | 1 | $\bar{3}$ | M | 2·659 | S | 2·395 |
| 2 | 0 | 0 | M | 2·514 | VS | 2·343 |
| 1 | 1 | 3 | M | 2·431 | M | 2·265 |
| 2 | 0 | $\bar{2}$ | | 2·427 | M | 2·255 |
| 0 | 2 | 0 | MS | 2·282 | VW | 2·203 |
| 2 | 1 | $\bar{1}$ | S | 2·212 | S | 2·157 |
| 2 | 0 | 2 | MS | 2·198 | S | 2·090 |
| 2 | 1 | 1 | MS | 2·117 | VS | 2·031 |
| 1 | 2 | 0 | VS | 2·078 | M | 2·006 |
| 0 | 1 | 5 | S | 2·058 | M | 1·931 |
| 2 | 0 | $\bar{4}$ | MS | 2·035 | W | 1·899 |
| 2 | 1 | $\bar{3}$ | S | 2·016 | S | 1·868 |
| 1 | 1 | $\bar{5}$ | S | 1·990 | W | 1·794 |
| 0 | 0 | 6 | S | 1·972 | MS | 1·785 |
| 1 | 1 | 5 | MS | 1·829 | MS | 1·777 |
| 2 | 1 | 3 | MS | 1·820 | MS | 1·767 |
| 2 | 0 | 4 | MS | 1·779 | S | 1·753 |
| 1 | 2 | $\bar{4}$ | S | 1·732 | | |
| 2 | 1 | $\bar{5}$ | MS | 1·695 | | |
| 2 | 2 | 0 | VW | 1·690 | | |
| 2 | 2 | $\bar{2}$ | W | 1·663 | | |
| 2 | 0 | 6 | M | 1·636 | | |

VS = very strong; S = strong; MS = medium strong; M = moderate; W = weak; VW = very weak

powder-diffraction pattern has not yet been indexed (Table II) and the formula assigned to this carbide, $Mn_7C_2$, can only be accepted as a preliminary one.

Manganese, lying between chromium and iron in the periodic system, forms carbides isostructural both with chromium carbides ($Cr_7C_3$, $Cr_{23}C_6$) and with cementite ($Fe_3C$). Carbides isomorphous with $Mn_7C_2$ and $Mn_5C_2$ have not been found in any other metal–carbon system.

Isobe (*op. cit.*,[5] pp. 468–490) reported a carbide $Mn_4C$ which was said to be stable below 1000° C.; this is perhaps the $Mn_{23}C_6$ carbide. His α-carbon ($Mn_2C$) and β-carbon solid solutions have not been confirmed. Also mentioned in the literature is a ferromagnetic $Mn_4C$ carbide,[17] isostructural with the f.c.c. $Fe_4N$ and $Mn_4N$.[18] This phase has also been encountered[6] in that part of the sample which during heating came into direct contact with the silica tube. Chemical analysis showed a lower proportion of carbon than that corresponding to the formula $Mn_4C$; this suggested that part of the carbon is replaced by the oxygen picked up from the silica tube. This phase, though ferromagnetic, is not stable below 800° C., and thus cannot be the ferromagnetic $Mn_4N$ which is stable below this temperature.[18] It is suggested that this phase is an interstitial carboxide $Mn_4(C,O)$ rather than a pure carbide.

## EXPERIMENTAL METHODS

Manganese is a very volatile and easily corroded element, and its carbides decompose rapidly in air. Alloys containing much manganese are extremely brittle, and it is very difficult to prepare them for metallographic examination. For these two reasons, the constitution of the Fe–Mn–C system was studied by powder-metallurgy and X-ray diffraction methods.

The weighed powdered mixtures of iron (Schering-Kahlbaum, puriss), manganese (electrolytic, distilled, 99·9%), and carbon (Tierkohle, Schering-Kahlbaum) were heated *in vacuo* in silica tubes. Since manganese reacts with silica when they are in direct contact and forms in the presence of carbon the manganese carboxide $Mn_4(C,O)$, it was found necessary to separate the metal from the silica by putting the sample in a small alumina tube. The heating time varied with the temperature, and the following heating times were found to suffice for equilibrium: 1050° C., 24 hr.; 910° C., 100 hr.; 690° C., 500 hr.

Since some carbon was unavoidably lost during evacuation of the silica tube, the sample always contained less carbon after heating than as weighed. The manganese content of the sample showed no significant change, however, and therefore only the carbon analysis was performed throughout this investigation. The X-ray analysis was made by using an evacuated Guinier camera with monochromatized $CrK_\alpha$ radiation.

The method used in the present investigation to prepare and examine the Fe–Mn–C alloys was found to be very convenient, but some inherent disadvantages should also be pointed out. For instance, Öhman, in the discussion to a paper by Gayler (*op. cit.*,[9] p. 344), found it extremely difficult to suppress the β-Mn → α-Mn transformation when powder specimens were quenched from above the transformation

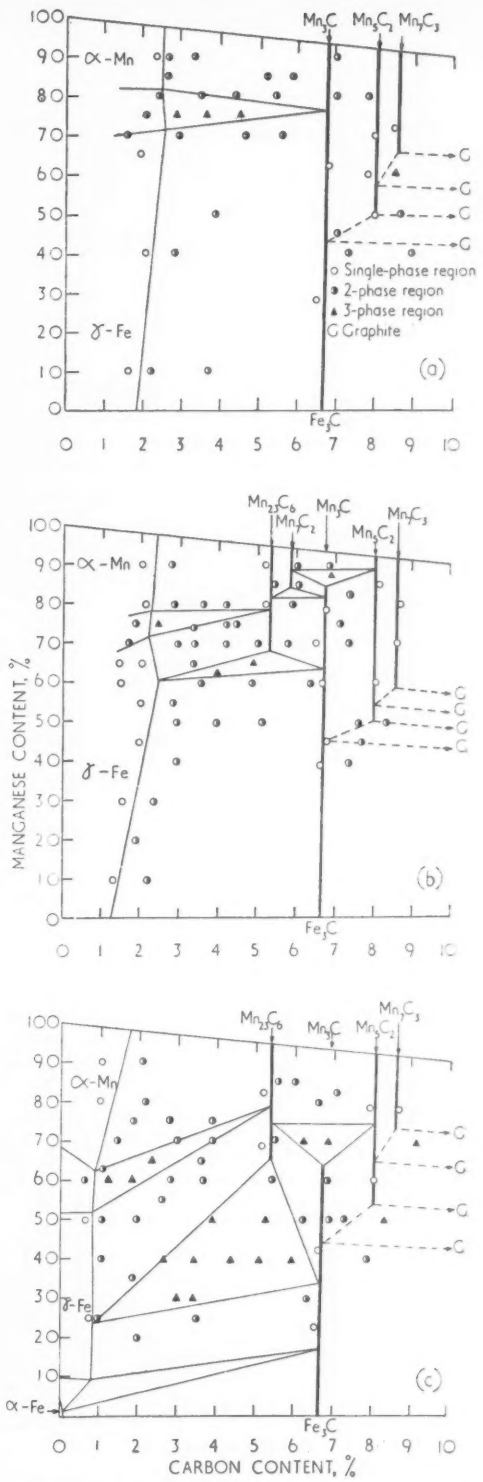
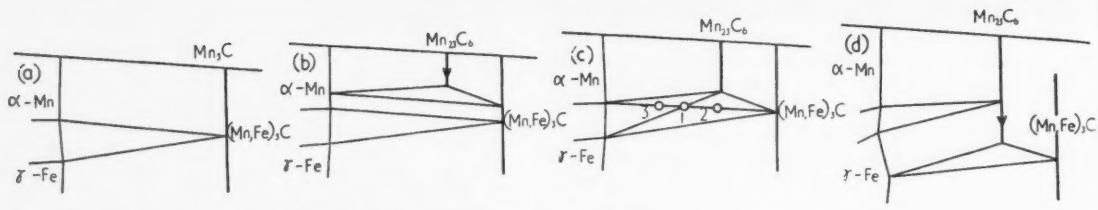



**Fig. 3—Constitution diagrams of ternary system Fe–Mn–C at (*a*) 1050° C., (*b*) 910° C., (*c*) 690° C.**




(*a*) At 1050° C., $Mn_{23}C_6$ is not stable

(*b*) At 1000° C., $(Mn,Fe)_{23}C_6$ is formed by the binary peritectoid reaction:
$\alpha\text{-Mn} + (Mn,Fe)_3C \rightarrow (Mn,Fe)_{23}C_6$

(*c*) At the invariant temp. $t_{PI}$:
$\alpha\text{-Mn} + (Mn,Fe)_3C \rightarrow \gamma\text{-Fe} + (Mn,Fe)_{23}C_6$

(*d*) At 910° C., $(Mn,Fe)_{23}C_6$ is formed by the binary peritectoid reaction:
$\gamma\text{-Fe} + (Mn,Fe)_3C \rightarrow (Mn,Fe)_{23}C_6$

**Fig. 4—Appearance of $(Mn,Fe)_{23}C_6$ (schematic)**

temperature. This may be the reason why the phase transformation temperature found by the powder-metallurgy method is sometimes higher than the real one. In addition, the X-ray disappearing-phase method for the determination of the constitution diagram is less sensitive than the conventional microscopic method. The Guinier camera used here can identify the presence of a phase when it is above 1%.

## ISOTHERMAL SECTION

### At 1050° C. (Fig. 3*a*)

At this temperature the carbide $Mn_3C$ is stable and forms with its isomorph $Fe_3C$ a series of solid solutions $(Mn,Fe)_3C$. Carbides $(Mn,Fe)_5C_2$ and $(Mn,Fe)_7C_3$ are also stable, but they never occur together with the metal phases.

It was rather surprising to find the existence of α-Mn at this temperature in equilibrium with $(Mn,Fe)_3C$, since the stable form of pure manganese at this temperature is β-Mn. Two explanations may be offered to account for this phenomenon. Firstly, the solution of carbon in manganese raises the β-Mn → α-Mn transformation temperature. Secondly, this transformation, as already pointed out by Öhman in discussion (Gayler, *op. cit.*,[9] p. 344), may occur at such a speed in powder samples that it cannot be suppressed by quenching. At present it has not been ascertained which of these two factors is the more important.

The presence of fairly high proportions of free carbon together with carbides in some of the alloys may be detected by examination of powder samples under a microscope.

### At 1000° C.

This isothermal section was only partially investigated. At this temperature the carbide $(Mn,Fe)_{23}C_6$ becomes stable and introduces a three-phase region $[\alpha\text{-Mn} + (Mn,Fe)_{23}C_6 + (Mn,Fe)_3C]$ to the constitution diagram (*see* Fig. 4*b*). Since the carbide $(Mn,Fe)_{23}C_6$ contains only a small amount of iron at 1000° C., it occurs solely in equilibrium with α-Mn.

### At 910° C. (Fig. 3*b*)

This temperature was chosen because α-Fe will not appear in the constitution diagram and the carbide $Mn_3C$ is no longer stable. However, at this temperature the carbide $(Mn,Fe)_3C$ may contain as much as 85% of manganese.

As the temperature decreases, the carbide $(Mn,Fe)_{23}C_6$ becomes more stable and contains more iron, and therefore it even appears in equilibrium with γ-Fe.

At this temperature the carbide $(Mn,Fe)_7C_2$ also becomes stable and introduces the three-phase regions $[(Mn,Fe)_{23}C_6 + (Mn,Fe)_7C_2 + (Mn,Fe)_3C]$ and $[(Mn,Fe)_7C_2 + (Mn,Fe)_3C + (Mn,Fe)_5C_2]$ to the constitution diagram.

### At 690° C. (Fig. 3*c*)

After lowering the temperature from 910° to 690° C. the following changes are observed:

(i) The carbide $(Mn,Fe)_7C_2$ disappears from the constitution diagram
(ii) α-Mn becomes the stable form of pure manganese
(iii) α-Fe enters the constitution diagram
(iv) The solubility of manganese decreases in $Fe_3C$
(v) The three-phase region $[\gamma\text{-Fe} + (Mn,Fe)_{23}C_6 + (Mn,Fe)_3C]$ extends to alloys with only 20–30% Mn
(vi) The solubility of carbon in α-Mn and γ-Fe decreases.

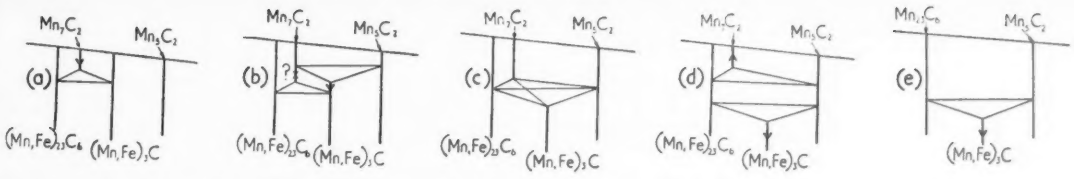
The low-manganese and low-carbon part (< 20% Mn, < 1·5% C) of this diagram is taken from p. 1251 of the "Metals Handbook,"[7] where the data are based upon more accurate microscopic examination.[1–3] The position of the phase boundary of $[\alpha\text{-Fe} + (Mn,Fe)_3C]$: $[\alpha\text{-Fe} + \gamma\text{-Fe} + (Mn,Fe)_3C]$ is based upon the partition ratio of manganese between cementite and ferrite, which according to Kuo and Hultgren[19] is 11·4 : 1, and according to Rose and Peter[20] is 11·6 : 1.

## DISCUSSION

### Ternary Peritectoid Reaction I

Below 1025° C., the carbide $(Mn,Fe)_{23}C_6$ becomes stable, occurring together with α-Mn at 1000° C. and later even together with γ-Fe at 910° C., as the solubility of iron in this carbide increases with decreasing temperature. It is of interest to examine how this reaction takes place.

Figure 4 shows schematically the series of phase changes including α-Mn and γ-Fe with decreasing




(*a*) Below 1000° C., $(Mn,Fe)_7C_2$ is formed by the binary peritectoid reaction: $(Mn,Fe)_3C + (Mn,Fe)_{23}C_6 \rightarrow (Mn,Fe)_7C_2$

(*b*) At 910° C., $(Mn,Fe)_3C$ disappears eutectoidally: $(Mn,Fe)_3C \rightarrow (Mn,Fe)_7C_2 + (Mn,Fe)_5C_2$. The carbide $(Mn,Fe)_7C_2$ may continue to form peritectoidally from $(Mn,Fe)_3C$ and $(Mn,Fe)_{23}C_6$, but it may also decompose eutectoidally to these two carbides

(*c*) At the invariant temp. $t_{PII}$: $(Mn,Fe)_3C + (Mn,Fe)_7C_2 \rightarrow (Mn,Fe)_{23}C_6 + (Mn,Fe)_5C_2$

(*d*) At a temp. between $t_{PII}$ and 850° C., $(Mn,Fe)_7C_2$ decomposes eutectoidally: $(Mn,Fe)_7C_2 \rightarrow (Mn,Fe)_{23}C_6 + (Mn,Fe)_5C_2$

(*e*) At 690° C., $(Mn,Fe)_7C_2$ has completely disappeared

**Fig. 5—Appearance and disappearance of $(Mn,Fe)_7C_2$ (schematic)**

temperature.* The three-phase region [α-Mn + $(Mn,Fe)_3C$ + $(Mn,Fe)_{23}C_6$] first moves downward with decreasing temperature (Fig. 4*b*) and finally joins another three-phase region [α-Mn + γ-Fe + $(Mn,Fe)_3C$] at an invariant temperature $t_{PI}$ between 1000° and 910° C. (Fig. 4*c*), which has not been exactly determined, but was found to be about 980° C. At this temperature, α-Mn reacts peritectoidally with $(Mn,Fe)_3C$, producing γ-Fe and $(Mn,Fe)_{23}C_6$. At composition 1, both α-Mn and $(Mn,Fe)_3C$ are consumed. At composition 2, some $(Mn,Fe)_3C$ is left in coexistence with γ-Fe and $(Mn,Fe)_{23}C_6$. At composition 3, some α-Mn is left in coexistence with γ-Fe and $(Mn,Fe)_{23}C_6$. Below $t_{PI}$, the two three-phase regions, [α-Mn + γ-Fe + $(Mn,Fe)_{23}C_6$] and [γ-Fe + $(Mn,Fe)_{23}C_6$ + $(Mn,Fe)_3C$], begin to separate from each other (Fig. 4*d*).

### Ternary Peritectoid Reaction II

Another point of interest is the appearance and disappearance of $(Mn,Fe)_7C_2$, shown in Fig. 5.

The carbide $(Mn,Fe)_7C_2$ begins to appear below 1000° C. through a binary peritectoid reaction (Fig. 5*a*), and the carbide $(Mn,Fe)_3C$ begins to disappear at 950° C. through a binary eutectoid reaction (Fig. 5*b*). The solubility of manganese decreases with decreasing temperature, and the three-phase region [$(Mn,Fe)_3C$ + $(Mn,Fe)_7C_2$ + $(Mn,Fe)_5C_2$] eventually joins another, [$(Mn,Fe)_3C$ + $(Mn,Fe)_7C_2$ + $(Mn,Fe)_{23}C_6$], at an invariant temperature $t_{PII}$ between 910° and 850° C. At $t_{PII}$, as shown in Fig. 5*c*, the carbide $(Mn,Fe)_7C_2$ reacts peritectoidally with $(Mn,Fe)_3C$ and produces $(Mn,Fe)_{23}C_6$ and $(Mn,Fe)_5C_2$. Below $t_{PII}$, the solubility of iron in $(Mn,Fe)_7C_2$ decreases with temperature (this may occur at a temperature above $t_{PII}$ (*see* Fig. 5*b*)) and this carbide disappears by decomposing eutectoidally into $(Mn,Fe)_{23}C_6$ and $(Mn,Fe)_5C_2$ as seen in Fig. 5*d*. This carbide finally disappears completely when the temperature is below 850° C. (Fig. 5*e*).

* Arrows are added to these isotherms to show the moving direction of the three-phase triangles with decreasing temperature, in the same sense as they are used in the polythermal projection of the temperature/composition prism of a ternary system. Strictly speaking, this is not correct, but such a presentation gives a clearer idea of the transformation processes.

### Carbide in Manganese Steels

There is no double carbide of iron and manganese in this ternary system, though the solubility of iron in manganese carbides and of manganese in cementite is quite large.

No other carbide than cementite is to be expected if the steel does not contain more than 20% of manganese. However, when the manganese content increases beyond this value, $(Mn,Fe)_{23}C_6$ first appears together with $(Mn,Fe)_3C$ and later replaces the latter completely. In chromium steels,[21] the sequence of carbides occurring as the chromium content increases is $(Cr,Fe)_3C$, $(Cr,Fe)_7C_3$, and $(Cr,Fe)_{23}C_6$. Unlike $(Cr,Fe)_7C_3$, the carbide $(Mn,Fe)_7C_3$ never occurs together with the metal phases.

The isomorphous carbides $Cr_{23}C_6$ and $Mn_{23}C_6$ also form a series of complete solid solutions $(Cr,Mn)_{23}C_6$. Since the addition of either chromium or manganese to steels promotes the formation of the carbide $(Cr,Mn,Fe)_{23}C_6$, it is to be expected that this carbide will occur in a chromium steel containing manganese at a lower chromium content than in a steel containing only chromium. This idea has been experimentally confirmed by Hofmann and Deponte,[22] who found that in steels containing 0·8% of carbon and 15% of chromium the stable carbide is $(Cr,Fe)_7C_3$. The addition of 8% of manganese to this steel changes the stable carbide to a mixture of $(Cr,Fe)_{23}C_6$ and $(Cr,Mn,Fe)_7C_3$. At 12% of manganese, this steel contains only $(Cr,Mn,Fe)_{23}C_6$.

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# The State of the Carbon in Austenite and Martensite as Revealed by the Eggertz Test

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SYNOPSIS

On the basis of the Eggertz colour test, carried out with the Spekker apparatus, it is shown that the colour is a linear function of the carbide present. On the assumption that any carbon present in the elementary form makes no contribution to the colour, it is shown that plain carbon steels quenched from the austenite area contain combined carbon, the amount of which increases with the carbon content and falls as the quenching temperature is raised; *i.e.*, the reaction $Fe_3C \rightleftharpoons 3Fe + C$ moves to the right as the quenching temperature becomes higher. It is concluded that the carbon is partly present in some form of chemical combination and partly dissolved in the elementary state. The X-ray evidence regarding the structure of austenite is reviewed, and is not thought to be inconsistent with such a hypothesis. Tempering curves show that this is a two-stage process, the first part extending up to about 120° C., and the second stage from about 200° C. to the highest temperature used (300° C.). These two stages are separated by a gap of 80–100° C., during which, so far as the colour test is concerned, the martensite is in a state of metastability. The results which have been obtained are consistent with the view that the carbide precipitated at temperatures below 120° C. is very probably Jack's $\epsilon$ form. 991

WITH the exception of the work of Whiteley,[1] the interest in the Eggertz test which was so pronounced a feature of metallographic research at the turn of the century[2] seems almost to have disappeared. In connection with the metallography of the iron–carbon alloys it still, however, seems to possess a potential value, and the main purpose of the present work is to examine the light which it may throw on the structure of austenite and martensite.

That austenite is an interstitial solid solution of carbon in $\gamma$ iron, and that martensite is a similar solution in the tetragonal or cubic $\alpha$ form, has been proved by numerous X-ray researches, but to what extent the iron and carbon are chemically linked, either as $Fe_3C$ or as some other ' compound,' is as yet very incompletely known. That compounds can exist in solid solutions is almost certain (*e.g.*, the very clear evidence for the existence of $Mg_2Si$ in the Al-rich $\alpha$ solid solution of the Al–Si–Mg system) and the presence of a compound $Fe_xC$ in austenite or martensite need therefore create no surprise.

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That the coloration produced in the solution of an annealed steel in nitric acid is due to the $Fe_3C$ has long been known, and the strictly quantitative relationship between them will again be demonstrated later. It is extremely doubtful whether elementary carbon yields any corresponding coloration; the colour carbon test, for instance, of a pig iron or malleable cast iron ties up well (possibly perfectly) with the amount of pearlitic carbide as determined metallographically, and is, in fact, the standard method for determining the combined carbon of such materials.

From the earliest days of research on the Eggertz test[2] it has been recognized that in quenched steels some carbon is present which does not contribute to the colour test, the so-called ' missing carbon.' It would appear to be self-evident that carbon can exist in steel in three, and in only three, forms; as free carbon (graphite), in the combined form, and as elementary carbon in solution. In graphite-free steels, the colour is demonstrably proportional to the amount of combined carbon, and the ' missing carbon ' must therefore necessarily be present in the only other possible condition, *i.e.*, in solution and in the uncombined, elementary state. This view is entirely consistent with the results of Whiteley,[1] who showed that the conclusion of Osmond and Werth, that the missing carbon had escaped in the gases produced during the test, was unsound. The carbon is therefore still in solution, but in a state which does not contribute to the colour.

It would seem to be justifiable, therefore, to assume as a basis for the present discussion that the intensity of the coloration is a proof (and presumably also a measure) of the presence of carbon in some combined form. This is an observed fact rather than a mere assumption.

## EXPERIMENTAL TECHNIQUE

The experimental work consisted in the study of the variation with heat-treatment of the colour in the Eggertz test of a series of plain carbon steels of varying carbon contents. The carbon contents of the steels used, which were of normal commercial composition, are given in Table I, the carbon contents being determined by combustion by experienced analysts.

### Table I

### COMPOSITION OF STEELS USED

| Steel Designation | C, % | Mn, % | Si, % | S, % | P, % |
|---|---|---|---|---|---|
| A | Armco | ... | ... | ... | ... |
| B | 0·15 | ... | ... | ... | ... |
| C | 0·20 | ... | ... | ... | ... |
| D | 0·31 | 0·74 | 0·22 | 0·037 | 0·044 |
| E | 0·40 | 0·62 | 0·22 | 0·035 | 0·036 |
| F | 0·47 | 0·59 | 0·12 | 0·040 | 0·032 |
| G | 0·69 | 0·15–0·30 | 0·15–0·30 | 0·05 | 0·02 |
| H | 0·79 | ,, | ,, | ,, | ,, |
| J | 0·91 | ,, | ,, | ,, | ,, |
| K | 0·98 | ,, | ,, | ,, | ,, |
| L | 1·05 | ,, | ,, | ,, | ,, |
| M | 1·18 | ,, | ,, | ,, | ,, |
| N | 1·40 | ... | ... | ... | ... |

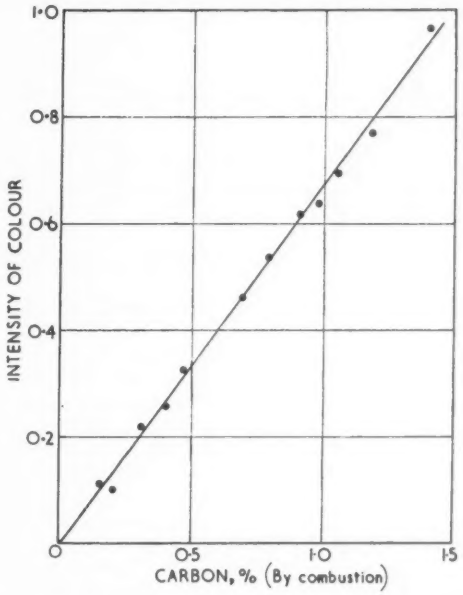



**Fig. 1—Intensity of colour as a function of carbon content (annealed steels)**

These samples were first homogenized for 2 hr. at the following temperatures and then slowly cooled:

| Steel | Annealing Temp., ° C. |
|---|---|
| *B* and *C* | 900 |
| *D* and *E* | 870 |
| *F* and *G* | 850 |
| Remainder | 815 |

To prevent decarburization, all specimens throughout the work were nickel-plated before heat-treatment, this coat being subsequently removed before test.

The determination of the colour of the solution was made with the Spekker absorptiometer, which offered the double advantage over the ordinary Eggertz test that, once calibrated against solutions of steels of known carbon contents, no further standard is required, and secondly that the personal factor is essentially eliminated. A constant ' water–water ' setting of 0·9* was adopted, and the colour intensity then taken as 0·9 minus the reading on the drum. A blue-green filter 603 was used throughout.

In the calibration, 0·1 g. of drillings was dissolved in 4 c.c. of 1·20 sp. gr. $HNO_3$, kept as cool as possible by immersion in cold water. When the vigorous reaction had subsided, the test tube was transferred to a beaker of boiling water. Tests on the steels with 0·91% and 0·31% of carbon had shown that the colour was lost rather rapidly during the first few minutes of heating at 100° C., the change then becoming much less rapid. The time of heating at 100° C. was, therefore, strictly standardized at 10 min. The

* Except in the case of steel *N*, where the intensity of the colour required a setting of 1·1.

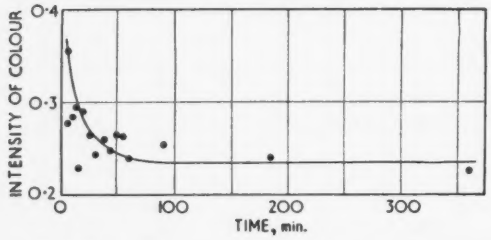



**Fig. 2—Effect of time at austenitizing temperatures**

cooled solution was poured into standard flasks, the test tubes being washed out with 1 c.c. of water for each 0·05 g. of drillings used. Eight determinations were made for each steel, the mean results being shown in Fig. 1. Under the experimental conditions adopted, and for the steels in the annealed condition, the ' intensity of colour ' = 0·68% C (by combustion) over the range of carbon contents from 0·15 to 1·40%.

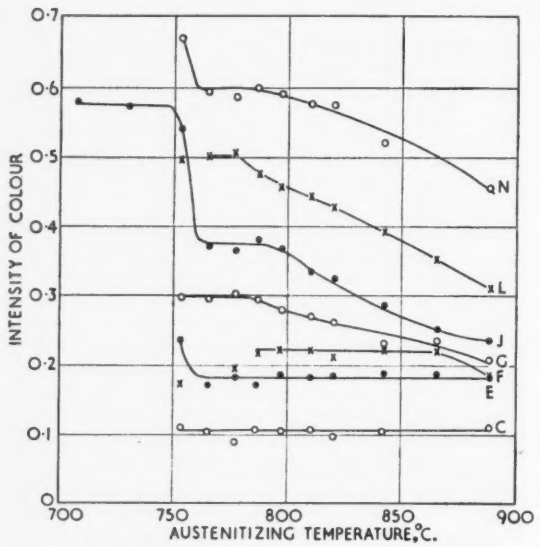
For the quenched, or quenched and tempered samples, strips 1 in. long × $\frac{1}{2}$ in. wide × $\frac{1}{8}$ in. thick were notched to a depth of $\frac{1}{16}$ in. every $\frac{1}{8}$ in. both along and across the specimens. These were later broken into cubes about $\frac{1}{8}$ in. square and weighing about $\frac{1}{4}$ g. The full specimen was nickel-plated before heat-treatment to inhibit decarburization, since neither ' vacuum ' treatment nor a nitrogen atmosphere proved to be completely satisfactory in this respect, the nickel being subsequently most carefully ground away. The plated specimens were heated in a Nichrome-wound tube furnace packed with kieselguhr and controlled by a Sunvic energy regulator, the temperature being measured with a chromel/alumel thermocouple. A mild-steel rod attached to the specimen enabled the latter to be quickly removed from the furnace and quenched in brine at room temperature. The small cubes were weighed after treatment and cleaning, and were dissolved as for the calibration, 4 c.c. of 1·20 sp. gr. $HNO_3$ being used for each 0·1 g. of the sample.

The effect of the time for which the steel was maintained at the high temperature was examined for steel *G* (0·69% C). Specimens were heated to 842° C. for periods varying from 5½ min. to 6 hr. and were then quenched and analysed as described. The results (Fig. 2) show that the colour falls substantially during the first hour at the austenitizing temperature, and thereafter remains more or less constant. In subsequent work, therefore, the heating time at the high temperature was maintained constant at 1 hr., a time much longer than would generally be regarded as necessary for equilibrium to be attained in plain carbon material only $\frac{1}{8}$ in. thick.

## EFFECT OF TEMPERATURE OF AUSTENITIZATION

The results of this part of the work are shown in Fig. 3, and two facts will at once be apparent. Firstly, there is a very marked fall on heating through $Ac_1$, and secondly, although the low-carbon materials thereafter show no further change up to almost 900° C., the intensity of colour (which will be assumed to be proportional to the amount of combined carbon) for the higher-carbon materials falls progressively as the temperature is raised.

In Fig. 4 the combined carbon (as defined) of the quenched steels is plotted as a function of the true carbon content of the steel and of the quenching temperature. As the temperatures of the phase changes for the conditions of heating used are not known, the equilibrium diagram, from which these should not differ materially, has been used. The broken line *AB* indicates the temperatures at which the colour begins to decrease rapidly, *i.e.*, at which a given intensity of colour is only attained in steels of higher true carbon contents.




*C* 0·20% C
*E* 0·40% C
*F* 0·47% C
*G* 0·69% C
*J* 0·91% C
*L* 1·05% C
*N* 1·4% C

**Fig. 3—Effect on colour of temperature of quenching**

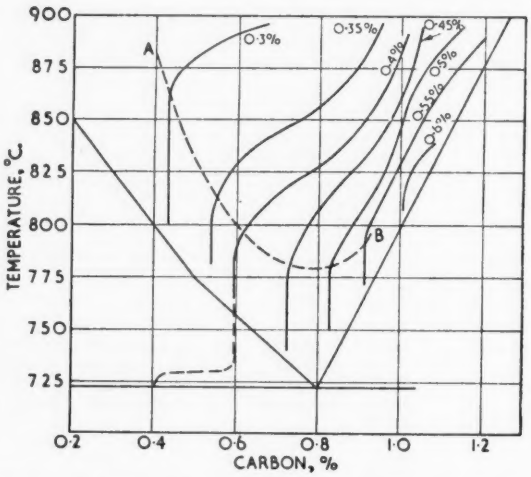



**Fig. 4—Colour carbon percentage of austenite as a function of temperature and the carbon content of the steel**

These results are consistent with the hypothesis that when a steel is heated above $Ac_1$ the carbon present in the combined form shows a sudden fall as pearlite is transformed to austenite. As the temperature rises further (except for the lowest-carbon steels), there is a further gradual decomposition of the carbide, which becomes more marked as the carbon content is raised. The temperatures at which this secondary decomposition becomes appreciable (line $AB$) fall to a minimum at about the eutectoid composition as the carbon in solution is increased.

The combined carbon content of the austenite for the 800° C. isotherm is shown in Fig. 5. For steels below 0·4% C a proportionate correction has been made to allow for the ferrite present in these steels, and above 1·0% the carbon present as free cementite has been subtracted. The curve therefore gives the combined carbon content of the austenite alone. Neglecting the entropy changes, and since $Fe_3C$ is slightly endothermic, this curve suggests for the steels in the fully austenitic condition a gradual increase of activity as this carbon content rises.

Figure 6 shows the curves for four austenitizing temperatures, together with that for the annealed steels, from which the ' missing carbon ' can be computed. This ' missing carbon ' (*i.e.*, that not reported by the Eggertz test) increases both with the temperature to which the steel was heated and with the carbon content, and in terms of the present hypothesis represents the carbon present in solution in the elementary, as distinct from the combined, form. The reason for the curious bulge around the eutectoid composition may possibly be connected with the fact that steels of this carbon content are superheated most above their upper transformation point, and have therefore had the maximum opportunity for the combined carbon to decompose. A sample of steel $J$ (0·91% C) quenched at 730° C. probably just below $Ac_1$ showed a ' missing carbon ' of about 0·05%.

## EFFECT OF TEMPERING

Six series of specimens, four of steel $L$ (1·05% C) and two of steel $H$ (0·79% C), were prepared and treated as follows:

| Steel | Austenitized 1 hr. at and Quenched from: | Tempering |
|---|---|---|
| $L_1$ | 865° C. | (*a*) $L_{1a}$, $L_{2a}$, and $H_a$ were at once tempered at temperatures up to 300° C. for ½ hr. |
| $L_2$ | 900° C. | |
| $H$ | 880° C. | (*b*) $L_{1b}$, $L_{2b}$, and $H_b$ were first quenched in liquid air and then tempered as above. |

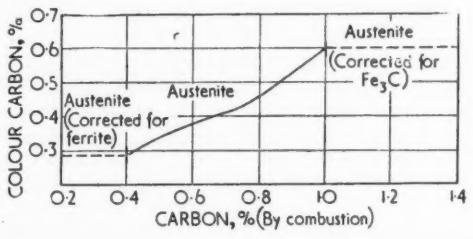
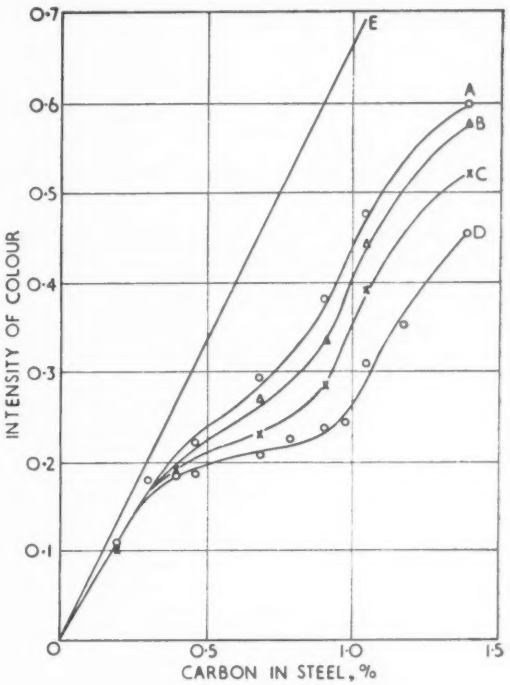



**Fig. 5—Combined carbon content of austenite present at 800° C.**

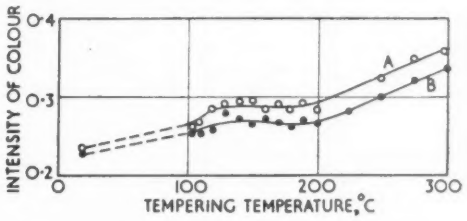



*A* Austenitizing temp. 787° C., 1 hr.
*B* ,, ,, 810° C., ,,
*C* ,, ,, 842° C., ,,
*D* ,, ,, 888° C., ,,
*E* Curve for annealed steels (from Fig. 4)

**Fig. 6—Comparison of colour/carbon-content curves for steels after various austenitizing treatments and for annealed steels**

The tempering was done in a Hearson air oven with an automatic control sensitive to ± 1° C.

The results plotted in Fig. 7 are typical of all six sets. The changes in the combined carbon consist in each case of (*a*) an increase (the exact shape of this part of the curve was not determined) up to about 120° C.; (*b*) a period of chemical stability up to about, or just over, 200° C.; and (*c*) a further increase up to the highest tempering temperature used. This sequence was clearly shown by each series of tests. From the point of view of the chemical behaviour of the steels, tempering is a two-stage process, the stages being separated by almost 100° C.




*A* Austenitized at 880° C. for 1 hr., brine quench
*B* ,, ,, ,, ,, ,, liquid-air quench

**Fig. 7—Comparison of colour/tempering-temperature curves for steels given different austenitizing treatments**

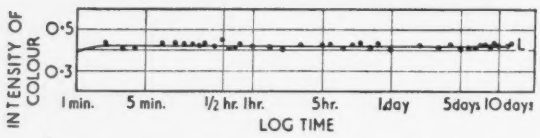



**Fig. 8—Effect of time of tempering at 150° C. on 1·05% C steel**

This gap between the two stages of the tempering process appears to be so important that samples of steel *L* (1·05% C) and *H* (0·79% C) were austenitized at 880° C., quenched in brine, and then tempered at 150° C. for periods of up to 12 days. The tempering was carried out in an oil bath heated in an electric furnace controlled by a Sunvic regulator, the oil being continuously stirred throughout. The results for steel *L*, typical of both series, are shown in Fig. 8. After a small initial rise during the first 2 or 3 min., the intensity of the colour remained quite unchanged within the limits of experimental error up to the full period of 12 days. During this period of tempering, the Vickers hardness number fell from about 850 to 630. That the gap is a zone of real chemical quiescence can then hardly be doubted; the progressive fall in the hardness must be attributed to the relief of lattice strain due to the shear which occurred during the formation of the martensite.

The consistent lowering of the combined carbon as determined by the colour due to the liquid-air treatment is unexpected. Precipitation of carbide, if the present suggestion of a partial decomposition of this in the austenite be justified, would have the opposite effect. If the precipitation phase is elementary carbon, its removal by upsetting the equilibrium between the free and the combined carbon, thereby reducing the concentration of the latter, would explain the observed results, but the difficulty would then be to explain why the process stops, only to restart when the temperature is raised about 100° C. In the discussion of these results a new hypothesis will be proposed.

It has been shown[3] that if water-quenched steels are aged at room temperature before being cooled to subnormal temperatures, the amount of retained austenite transformed to martensite is reduced. Samples of steel *L* (1·05% C) were austenitized for 1 hr. at 880° C. and quenched. One set was at once cooled to 0°, − 50°, − 100°, − 130°, and − 196° C. A second set was aged at room temperature for 1 hr. and similarly treated, the third set being first aged for 12½ hr. Although the results are almost on the limits of experimental error, there does seem to be a suggestion that the colour change is greatest for the unaged series and least for that aged at room temperature for 12½ hr.

## DISCUSSION

In discussing these results the authors disclaim any intention of being dogmatic. A neglected technique has been applied to the problem under examination, and the results are interpreted in terms of this.

The fact that when a steel is quenched from the fully austenitic area the Eggertz test gives a definite and reproducible colour carbon figure is the basis of the authors' belief that even in solid solution some atomic aggregation of the carbon and the iron, comparable to a carbide, does occur. The remainder of the carbon is presumably in solution in the elementary state, and at any temperature and for any given carbon content some equilibrium between 'combined' and free carbon seems to be demanded by the law of mass action ($Fe_3C \rightleftharpoons 3Fe + C$); on this basis the concentration of the undecomposed iron carbide should be proportional to that of the free carbon formed. As the temperature rises, the progressive decomposition of the carbide would be expected, in complete agreement with the fact that for a given steel the intensity of colour falls as the temperature of quenching rises.

The fact that either iron carbide or graphite may be precipitated from austenite, although no proof, is at any rate not inconsistent with the view that carbon is present in solution in both forms. Such a view is more satisfying to the metallographer than an explanation based on the assumption that there are two different forms of austenite.[4] That the graphite line lies at lower carbon contents than the cementite line can be interpreted as implying that the elementary carbon strains the lattice to a greater extent than does carbon in the combined state, its precipitation therefore bringing about a greater degree of relief from lattice strain. That graphite is rarely precipitated from the austenite of the steels, and even then usually under conditions of very slow cooling, is probably explicable on the basis of the relative complexity of the embryo of the graphite lattice. In the formation of carbide it would seem necessary only for a single carbon atom to come into a special spatial relationship with two sets of three iron atoms, whereupon such embryos of carbide should form with comparative ease. In the case of graphite, however, a number of carbon atoms must occur simultaneously on the same plane and in a suitable state of distribution with regard to each other.

Figure 4 shows that the lines of equal intensity of colour are essentially vertical at temperatures just above the phase boundaries, but that at some higher temperature they bend over to the right. This is consistent with the view that as the temperature is raised, the equilibrium of the reaction $Fe_3C \rightleftharpoons 3Fe + C$ moves to the right. Since the presence of carbon in solution in the austenite in any form must result in lattice strain, it is not surprising that as the carbon concentration rises (and with it the degree of lattice strain) the temperature of rapid decomposition (line *AB*) should fall.

That some of the carbon in austenite may be present in combination with the iron need cause no surprise. It has already been mentioned that in the case of the Al-rich solid solution in the Al–Mg–Si series there is an acute break in the lattice-parameter curve corresponding with the compound $Mg_2Si$. Furthermore, innumerable equilibrium diagrams show the presence of compounds existing in a state of solid solution over a range of composition. Numerous workers on the constitution of alloy steels have independently suggested the possibility of special carbides being present in the austenite in such materials. Both the 'spoiling' of tungsten magnet steels and the effect

of the initial temperature on the structure of chromium steels cooled at a constant rate have been ascribed to the dissociation or to the decomposition of complex carbides. If the austenite consists merely of atoms of carbon interstitially dispersed in the γ-iron lattice, even if some of the iron atoms are replaced by those of other elements, it seems impossible to visualize any process whereby such well-established effects could possibly be produced.

In the higher-carbon samples, and in particular those quenched in the higher temperature range, a certain amount of retained austenite will have been present. Although the evidence is merely negative, it is interesting that no clear differentiation between austenite and martensite in such samples has been obtained. The implication, so far as it goes, suggests that the carbon present in the combined form in the one remains combined in the other.

From time to time it has been suggested that iron carbide present in solution in the austenite may be in the form of associated molecules which dissociate as the temperature rises. The results of the present work seem to be inconsistent with such a view. Such dissociation would either yield the same coloration, since the same amount of carbon is still present in the combined form, or might even lead to an increase, since the molecular concentration of the carbide would be increased. It is difficult, too, to visualize what the physical structure of such an associated molecule would be.

The tempering results show that, from the chemical standpoint at any rate, tempering is a two-stage process, the first extending up to about 120° C., and the second from just over 200° C. upwards. These stages are separated by a temperature zone of 80–100° C., in which chemical metastability occurs, a conclusion in agreement with the results of Whiteley,[1] who also found over this temperature range no variation of the intensity of colour. The explanation of the second stage presents no difficulties. When a carbide passes into solution there is a partial decomposition; when the carbide is later reprecipitated, both elementary and combined carbon will be withdrawn from solution and the coloration will thereby be increased. To explain the first stage, and in particular why this is so sharply differentiated from the second, is less easy, but the following very tentative hypothesis may be suggested.

The transformation of austenite to martensite implies very severe mechanical shear of the lattice. In this shearing operation on almost every atomic plane the aggregates of carbon and iron atoms representing the combined carbon in solution must therefore suffer a large degree of break-up. Initially, therefore, it is possible to envisage in the martensite a most complicated distribution of the carbon, some in the elementary form, some still as $Fe_3C$, and some in the form of FeC, $Fe_2C$, or, in fact, almost any combination. The first stage of the tempering will therefore, on the basis of such a hypothesis, represent a recovery, with the re-formation of the combined form—probably Jack's ε phase,[5] "near to $Fe_3C$ in composition." Many other workers have postulated such an intermediate carbide phase. That the tetragonal lattice is at the same time reverting to the cubic will complicate matters still further from the point of view of physical measurements. Here the value of a chemical technique is shown to the full, since the picture is immensely simplified.

Once this process of recombination is completed, the period of metastability sets in, during which, according to Averbach and Cohen,[6] the lattice parameter also remains constant. At about 200° C. or just over, the martensite becomes so unstable that the normal precipitation of carbide begins to take place. Other workers have already noticed marked changes in certain physical properties at about 120° and 220° C., respectively. Enlund,[7] for example, has observed marked changes in the electrical resistivity of quenched steels tempered at these temperatures.

Since the variations on tempering investigated in this work are inherently associated with the mode of occurrence of the carbon, they lend no support to the suggestion[8] that the first-precipitated phase is a nitride.

The most curious effect on the tempering behaviour of a previous low-temperature treatment is one for which no adequate explanation can be offered. The intensity of colour plotted as a function of the tempering temperature gives curves which are essentially parallel both for the material which has been supercooled and for that which has not been so treated. The undercooling has had not merely a temporary, but a permanent influence on the results obtained, right up to the maximum tempering temperature of 300° C. used in this work. This makes it difficult to believe that the difference between the two curves is associated merely with the transformation on cooling to the low temperature of any residual γ iron. It would, however, be not inconsistent with the idea of the precipitation of two different carbide phases below 120° and above 200° C., respectively.[5, 8]

The authors do not intend to be drawn into a consideration of their results in relation to the mass of material obtained on the tempering process by physical methods. There is still a marked lack of unanimity in the interpretation of such physical tests, and, moreover, it would be manifestly unprofitable, since both the chemical and the physical approach can make its own contribution to the final solution of the problem. There is, however, one matter to which some attention must be directed. In certain X-ray investigations of the nature of austenite and martensite, it is at least tacitly implied that since it is not possible to fit the cementite lattice into the face-centred cubic lattice of γ iron, the existence of a compound in the austenite is impossible.[9]

The authors agree that there is no possibility of fitting the ideal lattice of the cementite into the ideal face-centred lattice of γ iron, but it must be remembered that the X-ray picture is merely an average, and that there is at the moment no technique available by which the distances between individual atoms can be measured. Furthermore, since no metallic crystals are ever perfect, the interatomic distances of the iron atoms will vary, quite apart from the fluctuations resulting from thermal agitation. The picture which has usually been presented has considered only the perfect static lattice, and dogmatic statements of what is or is not possible in the actual, imperfect,

fluctuating lattice of the austenite are therefore difficult to justify.

Whilst the authors accept Petch's view of the most probable sites for carbon atoms in austenite, it must be remembered that, even in a eutectoid steel, 95% of these sites would still remain unoccupied. They are, therefore, concerned not with fitting the cementite lattice into that of $\gamma$ iron, but merely with a chemical linkage between some of the carbon atoms present and the surrounding atoms of iron. The distortion of the lattice resulting from this combination would be highly localized and is not yet amenable to X-ray elucidation. They do not, therefore, accept the view that there is physical evidence to prove that the combination of iron and carbon in the austenite is impossible.

Cottrell[10] has suggested that the carbon atoms tend to migrate to the ' dislocations ' present in the crystal lattice. Without necessarily accepting all the superstructure which has been built on the established fact of crystalline imperfections, and which seems to be inseparably connected with the term ' dislocation,' the authors can still accept the general picture. At such crystalline imperfections, therefore, of which there must be an enormous number in each crystal of the austenite, almost any spatial relationship between the carbon and iron atoms may be possible.

Throughout this paper the use of either the term ' cementite ' or the formula ' $Fe_3C$ ' to describe the condition of the combined carbon in solid solution has been avoided. There is, in fact, no evidence available about the nature or composition of the ' carbide ' at the isolated points at which it is present in the lattice. Without, therefore, insisting on the same composition in the dissolved and the free states, it is significant as an example of what *may*, rather than what *does* occur, to point out that quite a small displacement of a carbon atom situated at the centre of the octahedron towards one of the octahedral faces will bring this atom into some special relationship to three atoms of iron. Such a state of affairs would answer Main's question[11] " Is it not possible that it (*i.e.*, the carbon) takes up some orderly formation from which each atom can readily associate itself with three iron atoms ? " Something of this kind must occur before the carbide can be precipitated. Since the displacement suggested is equally likely to be directed to any one of the eight faces of the octahedron, this would statistically be without effect in causing variation from cubic symmetry. It may be worth pointing out in this connection that statements to the effect that no displacement of the carbon atom could produce results corresponding to the observed effects seem to be unjustifiably dogmatic. Whether the displacement affects the observed result or not must depend on its magnitude.

This discussion will perhaps explain why the authors do not accept the view that the possibility of combined carbon existing in austenite has been disproved by X-ray evidence.

A consideration of martensite leaves the authors even less impressed by the significance of the evidence available.[12] The broadening of the X-ray lines is a clear indication both of the intensity of the strain and of the variation of this strain from point to point. As a result of the atomic movement required to convert the face-centred into a body-centred lattice, both the iron lattice itself and the distribution of carbon within it must be highly irregular. Arguments based, therefore, on the ideal static body-centred-cubic lattice cannot possibly represent the conditions which in fact obtain. The extreme degree of distortion of the martensite structure in high-carbon steels, for which evidence drawn from many directions contributes, suggests that the chances of the carbon atoms finding suitable sites would be increased in comparison with the relatively more perfect crystals of austenite. Furthermore, the expansion of the lattice should again provide an increased number of possible sites for carbon penetration, whilst, in addition, the atomic diameter of the iron in the $\alpha$ state is smaller than that in the $\gamma$.[13] In general, therefore, it seems likely that the solubility should be higher in martensite than in austenite, and that the chances of the carbon atoms finding suitably disposed neighbours would be greater. On the face of it, therefore, the quenching operation would not be expected of itself to cause precipitation.

The authors hope that they have provided, on the basis of chemical tests, an account of the states in which the carbon is present in austenite and martensite that is coherent and self-consistent enough to warrant serious consideration.

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# AFFILIATED LOCAL SOCIETIES

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# Sinter-Plant Operation at Appleby-Frodingham

*By N. D. Macdonald*


SYNOPSIS

The development of sinter-making at Appleby-Frodingham over the past 20 years is briefly outlined, together with the plans for the immediate future. Present-day sintering practice is described, with emphasis on the degree of plant control required when making a self-fluxing sinter from U.K. ores. Finally, outstanding problems of maintenance, design, and plant operation are surveyed. 886


## Introduction

SINTER-MAKING began at Appleby-Frodingham in 1934, following the installation of a 2-pan Greenawalt plant. This plant produced sinter at the rate of 3500 tons per week up to 1936, when two more pans were added, doubling the output.

With the building of the South Ironworks plant, an integrated ore-preparation plant was installed, which included two continuous sintering machines with a total capacity of 12,000 tons per week. These machines went into commission in 1939. In 1950, a general extension to the ore-preparation plant included two more continuous machines, with considerable modification to the original machines. At present there are four continuous machines in operation, with a total output of about 30,000 tons per week, with the Greenawalt plant producing a further 7000 tons per week.

A further extension to the ore-preparation plant now in progress includes four more continuous machines. In 1954, eight continuous machines will be in operation, with a total capacity of 65,000 tons per week. Thus, the weekly output of 1934 will be the shift output of 1954.

In common with all other plants, sinter-making started not from choice but from necessity, in order to consume the increasing proportion of fines in the mined ore. As this proportion increased, the furnaceman, by his demand for cleaner ore burdens, forced the rejection of more and more fines. Sinter-plant capacity was increased unwillingly, as the furnaceman regarded the higher proportions of sinter he had to carry in his burden as being the penalty he had to pay for clean ore.

After the 1950 extension the furnaces had to carry 45% of sinter in the burden to consume the fines arising from the mining and processing of the lump ore. Future trends were that within a few years this figure would rise to 63% of sinter and, as at the same time extensions to the ironmaking capacity were being planned, the provision of further sintering capacity was inevitable.

Trials were made to assess the effects of 63% of sinter in the burden, and this proportion was further increased, in stages, up to 100% of sinter. The performance of those furnaces operating on 100% of sinter was sufficiently gratifying to indicate clearly future ironmaking policy. The sintering capacity now being installed will, when in full operation, allow all pig iron to be made solely from sinter. The clean lump ore which the furnaceman once demanded will be deliberately crushed down to be made into the sinter he now prefers. The incoming run-of-mine ore, from 6-ft. lumps to dust, will all be reduced to $-\frac{1}{4}$ in. for sinter-making; the processing of the ore burden will instead be applied to the sinter-plant burden.

The policy of all-sinter burdening results from the realization that there will be considerable benefits in blast-furnace operation when much of the work the furnace now has to do is done outside the furnace by plant which can do it more efficiently and cheaply.

At present, insufficient sintering capacity prevents the operation of all furnaces on 100% of sinter, but the two largest furnaces have been operating on 100%


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of sinter for a long time. This commitment demands new standards of operation in the sinter plant. When operating a self-fluxing practice using two low-grade ores only, the sinter maker becomes responsible for iron quality on the all-sinter furnaces, and must make any burden changes *via* the sintering mixture.

This paper is confined to the practice carried out on the continuous machines, and in order to discuss fully the techniques used in sinter-making, plant description has been kept to a minimum. Such information has been published in some detail.*

The layout consists of four machines operated in two pairs: *A* plant and *B* plant. Each pair of machines has a separate mixture supply system, but they share a common returns or recirculating system. It is proposed to follow the system, describing the various processes as they are reached. The flow of materials may be followed from Fig. 1.

## RAW MATERIALS

The various constituents of the sinter mixture, the percentage of each constituent, and the total weekly consumption when producing 30,000 tons of sinter in 150 hr. are:

| Material | Burden, % | Consumption, tons |
|---|---|---|
| Frodingham ore | 36·8 | 30,200 |
| Northants ore | 15·7 | 12,860 |
| Machine returns | 15·0 | 12,300 |
| Returned sinter | 25·0 | 20,500 |
| Flue dust | 2·0 | 1640 |
| Coke | 5·5 | 4500 |
| Total | 100·0 | 82,000 |

As the machine returns and returned sinter are continuously recirculating and the coke is totally burnt, the total amount of sinter produced depends on the tonnage of ore and flue dust consumed. The ores are carbonate ores which have a sintering loss of 30% due to volatiles, so that only 70% of the ore input is recovered as sinter. This high sintering loss is one of the main reasons for the high circulating load.

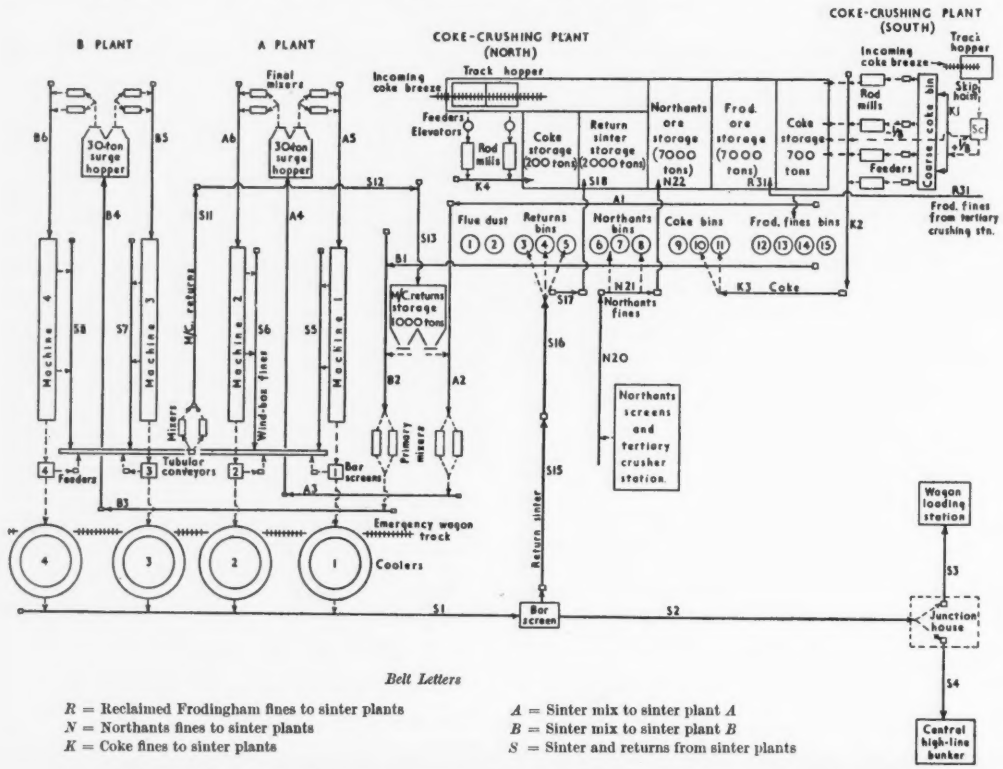
## MATERIAL PREPARATION

The sinter plant, like the blast-furnace, requires a prepared burden. Both the siliceous Northants ores and the limy Frodingham ores have disadvantages when used for making sinter; their sintering loss is 30%, they are of a very low grade, and the sintering bond is largely glass. The lime in the Frodingham ore exists as fossil shells. If such pieces are not crushed down they are converted to free CaO, and when embedded in a lump of sinter they finally disrupt the lump when the lime dehydrates.

It has been found from experience that if either type of ore enters the sinter plant in pieces larger than $\frac{1}{4}$ in., such pieces do not sinter thoroughly but are merely calcined. These pieces, when embedded in a lump of sinter, tend to collapse to dust, thus introducing planes of weakness in the sinter.

Another reason for material preparation is that the

* *Iron Coal Trades Rev.*, 1952, vol. 165, pp. 859–864, 909–915.




*Belt Letters*

*R* = Reclaimed Frodingham fines to sinter plants
*N* = Northants fines to sinter plants
*K* = Coke fines to sinter plants
*A* = Sinter mix to sinter plant *A*
*B* = Sinter mix to sinter plant *B*
*S* = Sinter and returns from sinter plants

**Fig. 1—Diagrammatic arrangement of material flow in sinter plants *A* and *B***

sinter maker, like the furnaceman, must control the size range of his burden to attain the higher permeabilities, which will allow increased air flow through the bed.

Under present-day conditions, the ore destined for use at the sinter plant lies within the range 1¼–0 in. The −¼ in. is screened out, through either orthodox or gas-heated screens, the +¼ in. passing through tertiary crushers before rejoining the screened −¼ in. delivered to the sinter plant.

The tertiary crushers are swing-hammer mills, which incorporate a moving breaker plate in the form of a manganese-steel apron. These mills are now being modified to incorporate two moving plates, one each side of the rotor, thus avoiding plugging troubles in the rear of the mill. Such a mill is now in use and is giving a good performance; an outline of the mill is shown in Fig. 2. The bottom of the mill is sealed by cage bars fitted with slots ¾ in. wide. This mill employs the normal hammer-mill crushing principles, but is especially adaptable for sticky ores, because the moving breaker plates are self-cleaning. Hammer wear is a problem, but intensive investigation into hard-facing is yielding promising results. Tungsten carbide is now being used on the hammer faces and the leading edge of the first cage bar. It is essential to distribute the feed over the full width of the rotor, otherwise hammer wear is uneven and crushing capacity is reduced.

The problems of hammer wear and inadequate tertiary crushing capacity still result in some +¼-in. material reaching the sinter plant. The penalties suffered more than justify the efforts to cure this problem.

The coke breeze received ranges in size from 1¼ in. down to dust, and varies in moisture from 5% to 20%. The coke must be crushed to a size suitable to the sintering mixture for which it provides the fuel. When the sintering mixture is distributed on to the pallet more coke is required in the upper layers than in the lower layers. Over-crushed coke will segregate too much in the upper layers, whereas under-crushed coke will segregate on to the grate bars and burn them. The practice followed is to crush to −⅛ in., avoiding a large proportion of −30 mesh.

Coke crushing is carried out in six rod mills, each of which is 12 ft. long × 6 ft. dia. and contains about 5 tons of high-carbon steel rods. The grinding chamber is lined with ' wave '-shaped liner plates which promote continuous rolling of the rods as the mill rotates at 20 r.p.m. The original charge is made up of mixed 3-in. and 2½-in. dia. rods; as these wear down to ¾ in. they are replaced by new 3-in. rods.

The operator controls the rate of feed into the mill by means of a vibrating feeder, which discharges into the scroll housed in the hollow inlet trunnion. The mill operates on the overflow principle, the coke being ground between the rods and discharged at the outlet end.

The size of the product is controlled by the operator, who adjusts the feed rate on the appearance of the coke. As the rods wear, the feed rate to the mill must be reduced to maintain the quality of the product. When the feed rate becomes unduly restricted, rod changes are necessary. Daily samples are taken and changes are made when more than 10% of +⅛ in. is detected in the product.

Each mill produces 5–7 tons/hr., depending on the moisture content and size range of the feed. The −⅛ in. is screened out before crushing, but mat blinding due to wet coke is a problem. Trials are being made continuously on various types of mill liner plates, as the rate of wear is high.

The flow sheet in Fig. 1 shows that there are two returns systems. The ' machine returns ' is the undersize (−¾ in.) rejected by the bar screens at the end of each machine. The ' returned sinter ' is the material −½ in., rejected by the bar screen after the

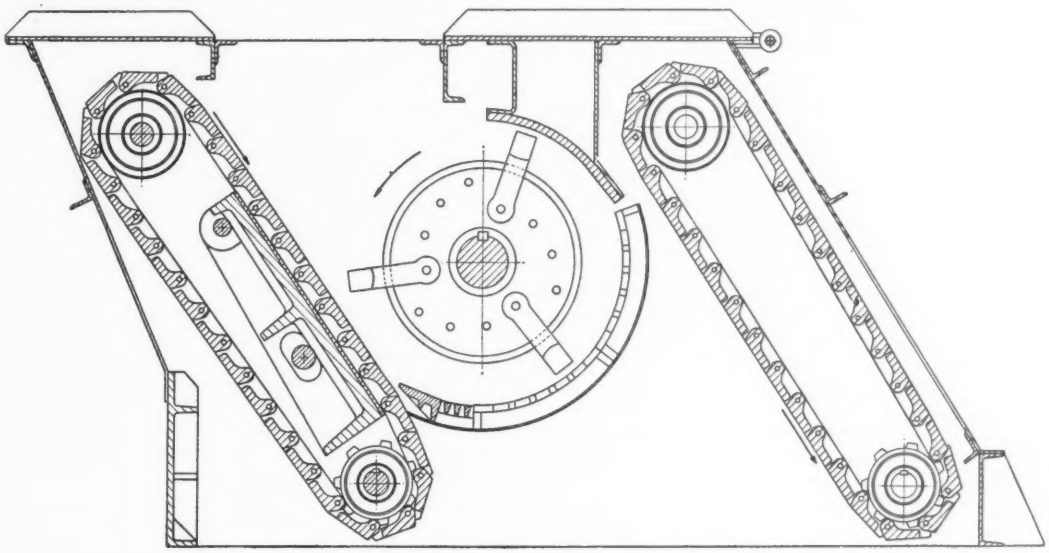


**Fig. 2—Moving-breaker-plate hammer mill with moving back plate**

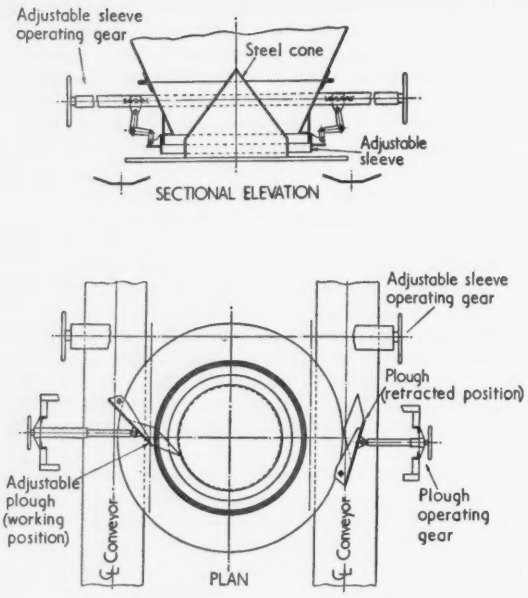



**Fig. 3—Arrangement of bin discharge**

coolers. Apart from quenching and the mixing of the machine returns, no further preparation is carried out, as the size range is governed by the screen setting to give the amount and size required in the mixture.

Flue dust arrives at the plant in the pugged state and is given no further treatment, being tipped directly into the bins.

The crushed ore, coke, and returned sinter enter the storage building and may be disposed directly into bins or discharged into storage, from which they may be recovered by two grab cranes. The machine returns are stored in a large bin. This storage capacity is considered vital, and is of special importance to the recirculating systems.

The importance of providing adequate storage or surge capacity at strategic points in the plant cannot be overstressed. The operators controlling each stage of the process must not be hampered by dislocations occurring in the sections behind them.

## PREPARATION OF THE SINTERING MIXTURE

The plant arrangements are such that the four machines are operated as two pairs, referred to as *A* plant (machines 1 and 2) and *B* plant (machines 3 and 4). Each plant has a separate mixture supply and control system. The returns systems are common to all machines up to the point where this material is disposed into bins or storage. Each plant may then draw on this material as required in exactly the same way as for the rest of the mixture constituents.

The 15 raw-material bins are arranged in line between two gathering belts (*A*1 and *B*1 in Fig. 1). The bins are conical in shape, having cylindrical necks discharging on to rotary feeding tables. The distance between the cylindrical bin neck and the table may be controlled between 1 and 5 in. by means of an adjustable sleeve. This sleeve is concentric with the bin neck, and is raised or lowered from a handwheel. A hollow steel cone sits on the table, the cone base being such that a gap of 7 in. is maintained between the bin neck and the cone base. An adjustable plough is positioned on each side of the bin, so that the table may discharge on to either of the gathering belts. The plough cannot be inserted beyond the adjustable sleeve, but a flat blade protrudes from the plough and passes below the sleeve and rakes clear the gap between the cone and the bin neck. This promotes the constant discharge of material on to the table. The general arrangement of the bin neck is shown in Fig. 3.

The height of the sleeve controls the depth and width of the collar of material spilled on to the table, so that when the plough is inserted to control the discharge from the table, most of the collar is taken off. If the collar is too deep and too wide for the required discharge rate, the sleeve must be adjusted, otherwise the plough must be partly withdrawn to skim off the outer periphery of material only, and the discharge rate becomes very erratic.

Each plant has a separate motor-generator set, under the control of the machine operator. The D.C. motors on each feeder table may be selected to either of these motor-generator sets, and in this way each plant is allocated enough tables to complete its mixture supply system, thus making each plant a self-contained unit. Once a table is selected to a particular plant, the appropriate plough is inserted to feed the gathering belt supplying this plant. The machine operator may vary the voltage supply to the table motors in order to vary the table speeds within the range 2–6 r.p.m., all tables running at the same speed for the same voltage supply. An additional device is provided on the coke-table motors only, whereby the machine operator, by adjusting the field weakening on the motors, can raise or lower these speeds independently. This allows the operator to make small adjustments to the feed rate, *e.g.*, to compensate for changes in coke moisture.

The feeder-table attendant adjusts the position of the plough on each table to provide the relative amounts of each constituent of the mixture. After warning the machine operator to make no speed changes, he checks these amounts by allowing a tray to pass along with the belt, and weighs the contents of the tray. After checking the weights with the target weights set by the supervisor, the attendant makes any necessary adjustments, and communicates the results to the machine operator, who enters them on a log sheet. With the mixture proportions settled, the machine operator may then vary the table speed to obtain the feed-supply rate required. Weight checks are made every 30 min. as a routine. A communication system assists in maintaining the close co-operation which is essential between these two operators.

The mixture preparation stage is vital to the sintering process, and has become even more so now that not only must the coke/mixture ratio be correct, but the ore to ore ratio within the mixture must also be

held to close limits to control the lime/silica ratio in the slags on the all-sinter furnaces.

## PRIMARY MIXING

After the addition of the machine returns (carried out in the same way as for other materials), the sintering mixture is discharged into the primary mixing station. As the name implies, this is regarded as a preliminary mixing stage only, further mixing occurring later in the system just before the material is fed on to the sintering machine.

Two-stage mixing is carried out for a number of reasons. The length of the mixers permits only 30 sec. mixing time, which is too short for adequate mixing. The mixture contains materials with differing moisture contents and differing affinities for water, particularly as the Northants ore has been dried. Only a small amount of water is added during the primary mixing and, as there is a time lag between primary and final mixing, total moisture tends to even out. This also encourages the coke to distribute freely amongst the mixture rather than to cling to the constituent which happens to be the wettest. Thus the primary mixing stage aids the more vital work to be done at the final mixing stage.

The mixer consists of a rectangular steel body containing two rotating paddle shafts. The paddle shafts are fitted with blades to which are attached renewable tips. Owing to the abrasion on the tips, these must be hard-faced. This hard-facing gives them a life of about 12 weeks. There is a standby mixer on each supply system to enable mixers to be changed over without a plant stoppage. Water is added through three tundishes placed at equal distances along the top of the mill body.

## SURGE HOPPERS

These are located at a high level at the back of the sinter-machine building. The hoppers are fitted with two outlet necks, by which the common feed to two machines is divided to supply individual feeds to each machine. To prevent material size segregation on the incoming belt being felt right through the hopper, thus producing differing feeds at each outlet, the material is spread around the hopper by means of a revolving chute in the hopper inlet. If only one machine is in use, the chute is locked in one position.

In addition to splitting the feed to each machine, the surge hopper absorbs temporary differences between feed rates from the mixture supply system and the consumption rate at the machines. This avoids unnecessary changes to strand speeds. The hopper is of real practical use if the machines have to be stopped and all the belts on the supply system are full. These belts may be emptied during the stoppage and maintenance carried out.

Each hopper is gunite-lined and has a capacity of about 30 tons. It is fitted with two automatic stock-line test rods with indicators in the control room. From the control desk the machine operator may control the table speeds between 4 and 10 r.p.m. to suit the requirements of the machines.

The surge hoppers are regarded as an essential feature of plant control, as they allow the operator to use the table speeds to control feed rates to the machines and retain the strand-speed adjustment to control strand conditions only.

## FINAL MIXING

At each plant the final mixers are located below the surge-hopper feeder tables, the arrangements being such that the feed from each table, *i.e.*, the feed to each machine, may be diverted into either one of a pair of mixers. The feed may be changed over to the standby mixer without stopping the plant.

Two types of mixer are in use; one is similar in design to those in use at the primary mixing station and the other is of the drum type. The drum is mounted horizontally on rollers, with a single paddle shaft arranged off-centre to the longitudinal axis, running through the drum. The shaft is fitted with blades, to which are attached renewable tips. A fixed hardened-steel blade keeps the interior of the drum scraped clean. The shaft rotates at 150 r.p.m. with the drum rotating in the opposite direction at 6 r.p.m. Mixing time on both types is about 30 sec.

During the final mixing, water is added to encourage the fine particles to ball together, so that as the material is spread on the sintering pallet the mixture bed will be permeable to air flow. Within the limits of the fan, the more permeability which can be attained in the bed, the more air will be drawn through the bed and the faster will be the sintering rate. Other factors can affect the sintering rate, but permeability is the overriding control. It is known that there is an optimum moisture above which permeability decreases as the balled-up fines collapse into sludge. In practice this optimum cannot be reached, owing to plant limitations. Where a machine is served by a twin-paddle-type mixer only, the water additions must be restricted, otherwise the mixer will plug in a very short time. Water additions are less restricted in the drum-type mixers, and the wear on the paddle tips is much less.

The machine operator must therefore add water within the operating limits of the equipment. This is done by means of a valve, electrically operated from the control room. Water additions are adjusted according to any change in the mixture or in the feed rate to the mixer. Normally, the total moisture content of the mixture is about 11%, but this is a misleading figure, as it is the degree of surface moisture which is important. The operator must aim at obtaining the maximum 'balling' effect with the minimum water addition, as the more water added the more coke must be used to drive the moisture from the sintering bed. Ideally, all added moisture should be retained on the surface of the particles only, as it is surface moisture which induces the particles to ball up and take on an outer covering of coke. Absorbed moisture does no useful work in this connection. Experience leads to preference being given to fine sprays for adding water rather than open pipes, in order to attain surface moisture. A time lag between primary and final mixing helps to even out total moisture, but a time lag must be avoided between the final mixer and the machine, otherwise surface moisture is absorbed, thus affecting the degree of

balling. Overhead water tanks are used to ensure constant pressure in the water supply to the mixers.

## FEEDING THE SINTER MACHINE

As the empty pallets come round at the feed end of the machine, the feed is distributed on to the pallet in such a way that size segregation takes place vertically, with the coke segregating towards the finer particles. This procedure is followed to prevent the grate bars being choked or burnt, the coarse particles, mainly returns, forming a protective layer over the bars. The finer particles at the top of the bed form a better surface for ignition, which is also helped by the greater proportion of coke in the upper layers of the bed. In general, less coke is required in the lower layers of the bed owing to the heat supplied from the upper layers during sintering, but no part of the bed is completely starved of coke. Size segregation also helps in maintaining the permeability of the bed.

The feed from the final mixer is conveyed into a rectangular rubber spout which is swinging from side to side, discharging on to a sloping steel plate running the full width of the machine. The angle of the plate is adjustable, so that as it runs off the plate the material ' rains ' down to strike a predetermined line along a vertical cut-off plate. From this feed line the material runs to its natural angle of repose, during which size segregation takes place. The general design must be such that the operator has an unobstructed view of the feed line.

In practice, little trouble is encountered with this equipment, and it does carry out its duty, provided that the spout and the plates are kept clean. The spout keeps cleaner if the rubber panels are not fastened too tightly but are allowed to flex. Care must be taken in adjusting the arc of the spout, otherwise side-to-side segregation results, which produces pockets of weak sinter. The angle of the sloping plate is seldom varied once it has been set, unless there is a big change in the materials to be sintered. A direct drop from the sloping plate on to the bed prevents the material from running to its angle of repose and retards size segregation. The height of the cut-off plate controls the bed depth, but this is seldom varied from the maximum of 14 in.

Whilst it is realized that reduced bed depths reduce the bed resistance, it has been found in practice that the increase in sintering speed is insufficient for a gain in output to be made. The friable zone at the top of the bed remains the same depth irrespective of bed depth, and the faster strand speeds required for shallow beds increase maintenance and make ignition more difficult owing to the reduced ignition time.

## IGNITION

The ignition of the bed top may be regarded as the first stage of the actual sinter-making operation. As the filled pallets pass underneath the cut-off plate the surface of the bed is lightly furrowed to increase the surface area, after which the pallet passes under the ignition hood.

The hood is situated over the first windbox and consists of an arc-shaped steel shell with a 7-in. thick refractory lining. Set into the brickwork at the exit end of the hood is a horizontal row of burner nozzles, to which gas and air are supplied from manifolds above the hood. Blast-furnace gas and coke-oven gas are mixed before passing through gas nozzles into the burners.

The angle of the burners is fixed so that the direction of the flame is counter-current to the strand travel, the flame impinging on the bed and spreading out to cover a large area. The bottom of the hood is water-cooled.

The operator aims at complete ignition across the bed. He burns enough gas to obtain a black top, but must avoid fusing the surface of the bed to such a degree that bed permeability is affected. Gas and air flows to the burner are regulated by dampers located near the hood, where the operator may examine visibly the effect of the adjustment and check on the recorders housed in the control room. Gas consumptions per hood at 110 in./min. strand speed are about 60,000 cu. ft. of blast-furnace gas and 7000 cu. ft. of coke-oven gas per hour, equivalent to 1300 cu. ft. of mixed gas per ton of sinter produced. It is possible to operate on either blast-furnace or coke-oven gas alone, but mixed gas is preferred.

Ignition time is the important factor, and in this respect 2-stage ignition has a great deal in its favour.

## SINTER MACHINES AND FANS

The two machines on *A* plant are 108 ft. long over 16 windboxes, and the two machines on *B* plant are 120 ft. long over 20 windboxes; all the machines are 6 ft. wide. The pallet frames are of cast iron, and to them are bolted cast-steel end sections which contain the wheel assembly and the sealing strips. The corners of the end section are the parts subject to heavy wear and must be periodically built up by welding. These detachable end sections were first developed at Appleby-Frodingham and are now very widely used. The pallet wheels are grease-sealed. Two types of bar are used: finger-type and sectional-type, both made of malleable iron. The sectional type is preferred, as these are much easier to change. The life of both types is about 9 months.

The machines have the usual safety features, such as shear pins incorporated in the sprocket drive and trip-out gear for pallet misalignment. A more unusual feature is that the heavy castings at the discharge end may be adjusted to control the ' break-away ' gap as the pallets pass round the discharge rail.

The wind mains are brick-lined, the dust downcomers being fitted with vacuum flap valves. There are no dustcatchers between the end of the wind main and the fan, this space being taken up by a large expansion chamber with dust legs.

All fans are double-entry type with vane control. The fans on *A* plant are each capable of handling 150,000 cu. ft. of waste gas per min. at 149° C., with a static suction of 21 in. W.G. On *B* plant each fan is rated at 200,000 cu. ft./min. at 177° C., with a static suction of 21 in. W.G. Fan motors are 1000 and 1200 h.p. on *A* and *B* plants, respectively.

## SINTER HANDLING

The sinter discharged from the machine passes down a chute and over a static bar screen, the oversize discharging into a rotary cooler. The cooler consists of a 48-ft. dia. feeding table carrying a **V**-shaped annular ring, which is filled with sinter as the cooler rotates below the machine discharge chute. With the cooler full, a plough is inserted which ploughs sinter off the table to feed on to a gathering belt at a rate equal to the cooler filling rate.

Sinter is contained in the cooler for about 4 hr., but insufficient cooling takes place to avoid the use of water, both on the cooler and on the belt system. Considerable breakdown results from this practice, and the steam evolved introduces many other problems. An improved type of air cooler is being installed on the new machines which should eliminate many of the existing problems.

The quenched sinter is passed over a bar screen, the oversize, normally $+\frac{1}{2}$ in., passing to the blast-furnaces. The undersize from this screen and the discharge chute screens is re-used in the sintering mixture as returns by means of the systems now described.

## THE RETURNS SYSTEMS

Before the 1950/1951 reconstruction, the sinter plant at Appleby-Frodingham, like so many others, had almost no storage capacity in which to absorb the returns screened out of the sinter. The process was compelled to re-absorb these fines into the mixture at the same rate as they were made. This in turn produced changes in the mixture which first affected the mixture, then the returns, and then the mixture again. Thus, at no time was the process really stabilized, simply because there was no effective control over the returns.

Sinter returns are important to any plant, but especially so at Appleby-Frodingham, where returns are used to compensate for the high sintering loss, as well as assisting bed permeability, etc. Returns occupy 40% of the sintering mixture, and the operator must have full control over this material if he is to avoid cyclic operation.

The existing plant has two returns systems, each of which is an independent self-contained unit. The machine operator need not worry about the feed rate carried on these systems, as both discharge into some form of storage, from which the operator draws the required amounts. Where once the mixture varied at will over a wide range from minute to minute, the operator now need only adjust the returns about once a day or less, to suit stock levels.

The ' machine returns ' system carries the $-\frac{3}{4}$-in. material taken out by the bar screens before cooling, and also the wind-box fines. The materials are passed through vibrating feeders into mixers, where they are quenched before passing on to a conveyor system for disposal into a surge bin of 1000 tons capacity.

The ' returned sinter ' system carries the $-\frac{1}{2}$-in. material taken out by the bar screen located at the head of the belt gathering the sinter discharged from all the coolers. After further quenching, this material is conveyed into bins or into a 2000-ton storage bay.

The quality of the returns reflects the quality of the practice, and only fully sintered returns are effective in maintaining good operation; poor returns are a liability. Should the returns system become badly contaminated with semi-sintered material (*e.g.*, after a power failure on the fans) the plant facilities make it possible to sinter this material only, and so clean out the system before reverting to normal practice.

## PLANT CONTROL

The control of each plant is centralized in a glass-fronted control room located on the machine floor, positioned so as to give the operator an unrestricted

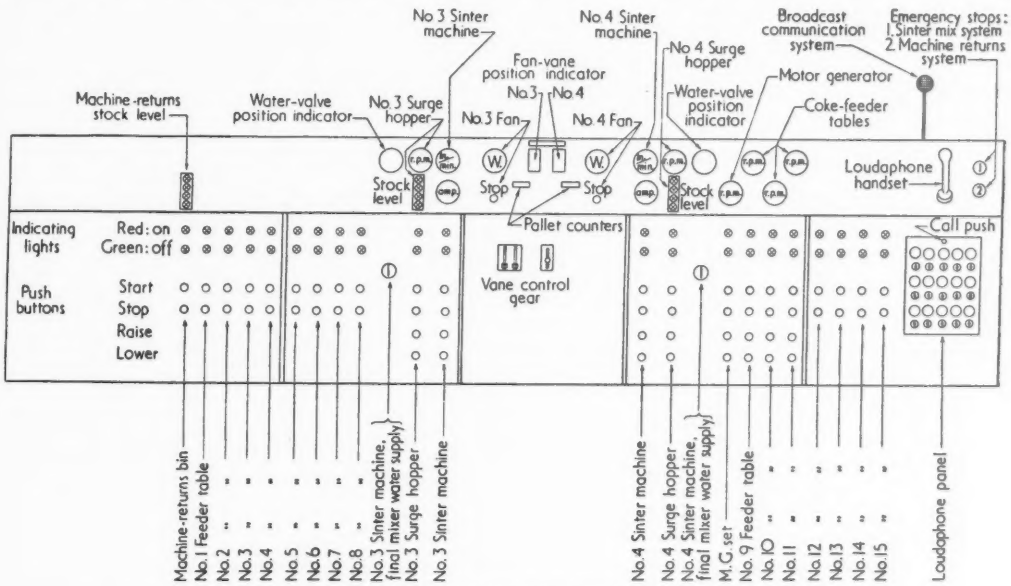



**Fig. 4—Sinter-plant control desk (machines 3 and 4)**

view of the feed end of each machine under his control. Each room contains an operating desk and instrument panel, the layouts of which are shown on Figs. 4 and 5. In addition to operating controls, there is a two-way communication system to all sections of the sinter plant and to the ore-preparation plant headquarters. A broadcast system covering the sinter-plant area enables the operator to call out instructions or ask for maintenance.

Probably the clearest picture of how the controls and instruments are used may be gained when the procedure carried out by the operator is considered in three stages:

Stage 1: Control of mixture supply to the surge hopper
Stage 2: Control of feed supply to the machine
Stage 3: Control of sintering operation.

**Stage 1**

In each control room there are controls and indicator lights for each raw-material bin. The indicator lights show the operator which bins have been allocated to his plant.

The machine operator instructs the feeder-table attendant to start up the tables required; the attendant does this in strict rotation to avoid lengths of belt being devoid of coke or other constituents. As the attendant starts each table, the lights change in the control room and signals appear on the gantry over the storage bins. The latter signals enable the gantrymen and crane drivers to keep a check on the bins to be kept under supervision.

The machine operator does not vary the table speed until the feeder-table attendant has set the ploughs to give the correct proportions. The operator then adjusts table speeds to give an input rate to the surge hopper consistent with the consumption rate of the machines. The controls thus used are:

(i) Raw-material table-speed control (M.G. supply) and speed indicator
(ii) Supply-belt weighmeter
(iii) Surge-hopper stock depth lights.

**Stage 2**

The surge-hopper table speeds are adjusted to maintain the feed line at the machines, just covering the bottom of the cut-off plates. Water is added in the final mixers by adjusting the electrically operated valve. Controls used in this operation are:

(i) Surge-hopper table-speed control and indicator
(ii) Water-valve control and valve-position indicator.

**Stage 3**

The ideal condition the operator aims for on the machine is maximum permeability of the bed, with strand speeds adjusted to complete sintering on the last but one windbox. When the operator attains these conditions, the volume of air available from the fan and the maximum available strand length are being used to the best advantage in maintaining high outputs. Water additions are left to the operator's discretion; the indicated suction on the windboxes and fan inlet can be used as a guide, but as they are subject to time lag they cannot be used as an effective minute-to-minute control. The operator aims at the lowest suction he can get, normally about 18 in. W.G. when the fan vanes are as fully open as the fan-motor load will allow. Thus, in addition to the suction indicators, the operator uses:

(i) Fan-vane control and position indicators
(ii) Fan-motor load indicators.

In adjusting the strand speed, the operator refers to the indicated temperatures on the windboxes and fan inlet. Normally, the strand speed is about 110 in./min., with the peak windbox temperature (about 450° C.) located on the last but one windbox. Again, the temperature indicators are subject to time lag in reflecting the strand conditions. In adjusting the strand speed the operator uses:

(i) Speed controls with strand-speed indicator
(ii) Ammeter on strand drive motor, to detect presence of faulty pallets, rails, blocked discharge chute, etc.

Control of fuel is important, and it is unfortunate that no positive method of indicating to the operator just how much coke to use has yet been devised. Coke requirements vary according to the condition

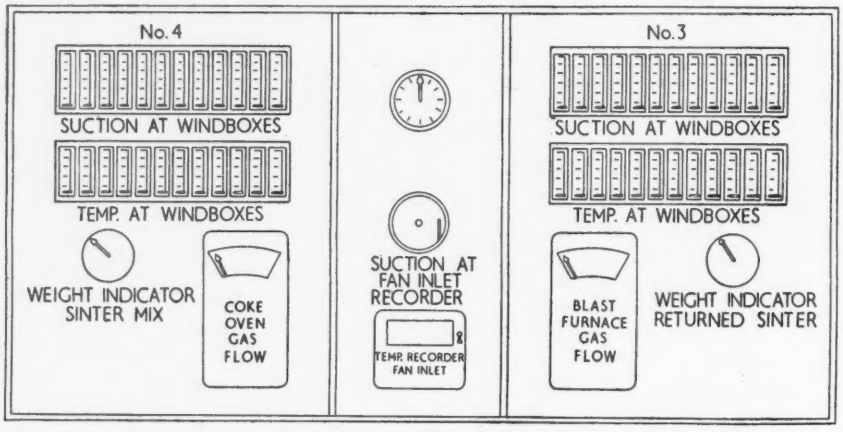



**Fig. 5—Sinter-plant instrument panel (machines 3 and 4)**

of the mixture, and the operator must primarily use his own judgment in adding coke to produce the required strength in the sinter cake. Coke feeds are adjusted by varying the speed of the coke table using the ' trimmer ' control, which allows the operator to vary the speed of this table without affecting the rest of the mixture. Speed indicators guide the operator in making these adjustments. The ' trimmer ' control allows the speed of the coke table to be varied 30% above or below the speed of all other tables. Should this limit be reached and further adjustment required, the feed from the bin must be adjusted. The general level of the windbox temperature gradient and the fan inlet temperature (normally kept at about 170° C.) are guides to coke requirements.

Although the time lag on the indicating instruments creates difficulties, by combining his experience with the intelligent use of the instruments the operator can detect changes in the strand condition and make adjustments in the early stages.

A mixture too high in coke shows up at the ignition hood, and the operator will temporarily add more water until adjustments become effective. Continued operation on too much coke will ultimately produce high indicated suctions and a flatter temperature gradient. The operator must then slow the strand down to compensate for the slower sintering rate. Under severe conditions, the fan-motor load will fall as less air is drawn to the fan, indicating that slagging is taking place and permeability is badly affected. Very slow speeds must be used until the corrective action, *i.e.*, coke reduction, becomes effective.

Too little coke will also show up at the ignition hood, and water must be reduced a little, even at the expense of a decrease in permeability. Increasing the ignition is no help. Continued operation with such a condition will ultimately result in the fan inlet temperature dropping.

A change to a denser bed will also produce high indicated suctions, and the peak windbox temperature will move further towards the discharge end of the machine. The fan-motor load will drop and the operator will make use of any increase in vane setting he may have in hand. Under conditions of reduced permeability, sintering rates are slower and the operator must reduce strand speeds until the effects of increased water additions are shown. A change to a more permeable bed will move the peak windbox temperature further back and suctions will fall. The operator may then speed up the strand in view of the faster sintering rate, but must not allow the peak temperature to go beyond the last but one windbox.

If very low suctions and a low fan inlet temperature occur together and the fan-motor load rises to the extent that vanes must be closed, the system is leaking badly.

Above all, the operator must keep the fan vanes open as much as possible within the limits of the fan motor, but must avoid the fan motor tripping out owing to overload. Any delay in restarting the fans may result in the whole strand length going ' dead.' When this happens, the full benefit of the self-contained returns system is felt.

The weakness in the control system lies in the difficulty experienced in distinguishing between changes resulting from variations in permeability and those resulting from variations in fuel. An effective minute-to-minute control over these variables will allow the operator to take corrective action with much more confidence.

## MAINTENANCE

It is doubtful whether there is any other process connected with ironmaking where the consistency and quality of product is so dependent on good maintenance. The sinter plant is virtually a moving chain of equipment, and is dependent on the strength of each link, however small. Less output is lost as a result of a single stoppage of 1 hr. than from three 10-min. stoppages occuring at, say, 30-min. intervals. Once the continuity of operation is lost, some time is required to stabilize the process after re-starting.

When the machines are stopped the fans must be kept running to allow the entire length of the bed to be sintered through. Conditions along the strand are therefore abnormal when the machine is restarted, and not until the full length of bed has been discharged can the operator begin to stabilize the process.

New standards of operation must be met by new standards of maintenance. Two years ago, a stoppage of 12 hr. every 10 days was considered inevitable; present practice caters for a stoppage of 16 hr. every 3–4 weeks, yet the standard of maintenance has been improved. The average weekly availability is 90%, but figures of 98% have been achieved.

This progress resulted from a patient and laborious programme of modification as weak spots were revealed. Many modifications had to be made on the trial and error basis before a satisfactory solution was found.

The problems of abrasion, particularly on the systems carrying sinter, were serious, chutes and liners being lost in 5 days. The introduction of impact boxes, together with chutes lined with ceramic tiles, has been most successful in this connection. The application of hard-facing to mixer paddle tips increased their lives from 1 to 12 weeks; similar success has been achieved on plough tips and screen bars. Work on hammer tips is proceeding and progress has been made. Rod-mill liner plates are also under investigation.

All problems of abrasion are investigated by a committee, on which operators and maintenance and research departments are represented, and every opportunity is given for trying out new ideas.

As more problems are resolved, more routine preventive maintenance measures may be applied. Each pallet goes off for maintenance every 40 weeks; pallet breakages are almost negligible now that ' wheel freezing ' has been cured. Grate bars are never allowed to become so worn that ' rat holing ' appears on the strand, as this means increased wear on the fan impellers. Grate-bar life is about 9 months and fan impeller life about 2–2½ years. Daily inspection is made on windboxes and mains for leaks in the system, as these must be attended to immediately.

Instruments are important items requiring regular maintenance. Once an operator loses faith in his instruments he will ignore them.

Close liaison between operating and maintenance sections is essential. Before each repair day, a meeting is held at which all sections of maintenance and operating departments are represented. This ensures that the full programme of maintenance is covered and gangs do not hinder each other.

Progress has been made, but there are many problems still remaining. Belt scraping is still poor, despite many attempts to cure this problem. Poor scraping introduces so many secondary effects that efforts must continue until this problem is solved. Generally speaking, little trouble is encountered with the sinter machines; it is the systems to and from the machines where further efforts are required. Nothing causes increased maintenance more than spillage and dust, items so often neglected in plant design.

## RECORDS AND MANPOWER

The machine operator keeps the shift log sheet on which delays, practice changes, mixture checks, etc., are recorded. The recording of certain operating data at intervals throughout the shift not only ensures that adequate information is available on the shift's activities, but also that the operator's attention is focused on important items affecting the practice.

The shift records are compiled into a daily summary which, with all recorder charts, etc., is examined each morning. Delays are classified and details passed back to the maintenance departments concerned.

Further summaries are compiled on a weekly basis. These records include screen and chemical analysis of all materials used during the week. Operating hours are extracted for all items of equipment on which special ' life ' tests are being carried out, *e.g.*, mixer paddles, screen bars, etc. Physical and chemical testing is carried out by an independent department; this information, with pertinent operating data, is submitted periodically for statistical examination.

In this way records are used to draw attention to weaknesses in the plant or practice, and at the same time create a background from which the problems of the future may be solved.

It has often been said that the only men who work in a sinter plant are those without enough sense to work somewhere else. Until recently the general appearance of the plants did not encourage men to take up sinter-making from choice, and very few had any pride in the job they were doing.

As the standard of plant and practice was improved, the ordinary man on the job felt he had a place in the sun, and with this came a pride in the job he was doing. The speed of technical progress was such that there was a danger that the plant would be ahead of the men operating it. Only by patient training could the suspicion of the men towards new ideas and the use of instruments be removed.

Unless the operator is trained to understand the controls and the help they will give him, he will go back to his old method of operation as soon as the supervisor's back is turned. If a man is intelligent enough to operate a machine without controls he can operate it much better with controls.

Most of the men in present-day sinter plants have at some time worked at a blast-furnace. Operators talk about the sinter bed being ' tight and not getting her wind.' In making mixture changes mention is made of ' taking lime off.' Probably the classic example was the cooler operator who, when an air-supply failure prevented him from withdrawing the plough, resulting in considerable spillage, said: " The gun stuck and I've filled the bogie road." In their minds, all these men are still making iron, which indeed they are. The future will see many men working on sinter plants who have never worked at a blast-furnace; they too must be taught that to make good sinter is to make good iron.

## FUTURE DEVELOPMENTS

Despite the progress made in the past few years, there is still plenty of scope for further improvement. Possibly the only real criticism of the machine itself is the high leakage on the strand and windleg discharges; it is the auxiliary processes where most present weaknesses lie.

Mixing must be improved, either by increased mixing times or different methods of mixing, or both. With furnace burdens controlled at the sinter plant, variations in the sinter mixture must be regarded in a new light. Improvements must be made to the present feeder-table methods, or better methods must be sought. A satisfactory solution to the air-cooling of sinter will remove one of the worst operating problems with which the sinter maker is faced. Water-quenching hot sinter, in addition to disrupting the sinter, produces a host of other problems. Methods of inducing permeability without the use of water would result in considerable fuel saving. The static bar screen, so long favoured in sinter plants, is hopelessly inefficient; the shallow screen-angles required for good screening necessitate the use of some form of moving screen. Dust extraction must be applied to a greater degree to remove the dust nuisance and the inevitable increased maintenance which results.

The machine operator must be given instruments to guide him in adjusting water additions, and in making correct fuel adjustments. A permeability meter now under trial will, if successful, be a valuable aid; in fact, it may well be the master control. So far, little is known about sinter quality, and work must continue to establish a more exact specification so that the sinter maker is aware of the standard he must attain.

In too many cases existing plants cannot apply the improvements already developed because of plant or site limitations. The plants built today must cater for the improvements of tomorrow.

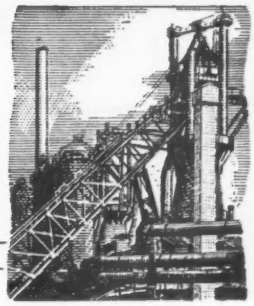
These problems cover many fields and involve many sciences; the sinter maker must not hesitate to seek the right sort of help to gain his objective. Above all, his aim must be the development of equipment to eliminate causes, and not the adoption of gadgets which merely minimize the effects.

## Acknowledgments

This paper represents the combined experiences of many colleagues on the Ore Preparation Plant, whose help the author wishes to acknowledge. He also wishes to thank the Appleby-Frodingham Steel Co. for permission to publish the paper.

# IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP



# THE IRON AND STEEL ENGINEERS GROUP

## *REPORT OF THE TWENTY-FOURTH MEETING*

THE TWENTY-FOURTH MEETING OF THE IRON AND STEEL ENGINEERS GROUP of The Iron and Steel Institute was held at 4 Grosvenor Gardens, London, S.W.1, on Thursday, 10th December, 1953. Mr. C. H. T. WILLIAMS, Chairman of the Group, was in the Chair.

At the MORNING SESSION the paper "Belt-Charged Blast-Furnaces of S.A. John Cockerill, Belgium," by Mr. G. HOOKHAM (John Miles and Partners (London), Ltd.), was presented and discussed. The discussion appeared in the August issue of the *Journal*.

At the AFTERNOON SESSION the paper "The Ironmaking Plant at John Summers and Sons (Shotton Works)," by Mr. J. F. R. JONES and Mr. A. WALKER (John Summers and Sons, Ltd.), was presented and discussed.

### Discussion on the Paper—

### THE IRONMAKING PLANT AT JOHN SUMMERS AND SONS (SHOTTON WORKS)*

Mr. **J. F. R. Jones** (John Summers and Sons, Ltd.), in presenting the paper, said : The layout of the plant was based primarily around a good railway system. In an integrated plant of this size one of the biggest problems was considered to be traffic, and care was taken to get an easily workable railway system. The different sections of the plant are rather widely scattered for two reasons : to give room for future extensions, and to get good railway facilities for every part of the plant.

In building the new plant, we had behind us the experience gained with foundations on the site when the strip mill was built in 1939. At that time pile foundations were used, and in regard to the blast-furnace plant there was much discussion about whether piles or rafts should be used. Advice was sought from an expert in soil mechanics and careful ground testing was carried out. It was found that it would be quite safe to load this sand up to about 4 tons/sq. ft., at which load the amount of settlement would be predictable. It was therefore decided to put only the blast-furnace plant on raft foundations. So far, the settlement seems to have taken place in accordance with predicted amounts.

The ore-unloading arrangements are a little out of the ordinary. The blast-furnace was designed to give its output on 75% foreign ore and 25% home ore, but we were always anxious to get as much foreign ore as possible to produce an iron which is suitable for making steel of the quality required for strip rolling. Arrangements were therefore made with the Mersey Docks and Harbour Board for a two-berth dock at Bidston, 14 miles from Shotton, connected to the works by a lightly loaded section of British Railways. Unfortunately, this line has to cross the very busy electrified lines serving the Wirral resorts from Liverpool. A shuttle service is used between Bidston dock and the works, but it has had to be very carefully worked out with the railways. The trains must run to a definite schedule to avoid this traffic and at the same time provide the necessary tonnage. The ore wagons are nominally of 46 tons capacity and have an axle load of 17½ tons.

Two ore unloaders are installed at Bidston dock. These are of 12½ tons gross capacity, with a useful lifting capacity of 6 tons. Only one machine is at present complete, but experience with the first has shown that its actual capacity is well up to expectations.

An ore bench has been built to give a quick turnround of the ore wagons. It consists of a line of 42 hoppers, each of 25 tons capacity. Trains will come in from Bidston with a load of about 750 tons of ore. The Company's own locomotives will split them at the sidings, and a complete half-train will go right on the line above the hoppers ; the doors will be dropped, and a complete train will be cleared ready to return to Bidston within an hour or two of entering the works.

We should like to use 100% of foreign ore ; at the moment some home ore is used. The ore bench did not work very well with this, because the sticky ore refused to come out of the wagon, and so a tippler was installed

*J. Iron Steel Inst.*, 1953, vol. 175, Nov., pp. 313–321.

on the end of the ore bench, discharging on to a bar feeder which in turn feeds on to the main belt. Underneath the row of hoppers there is a travelling plate feeder discharging on to the 60-in. belt. This moves along and operates the hopper doors, feeding a steady stream of ore on to the belt. The rest of the course of the ore is described in the paper.

The ore bridge is rather unorthodox, and the travelling gear will be of interest. Between 55% and 60% of adhesion is being obtained, and it works very well. The bridge has never been more than 3 in. out of square. Instead of having the grab running between girders, it runs on the upper flanges of the two main girders. On the far end of the bridge, on the side away from the furnace, there is a small goliath crane which can take any part of the grab out through the roof for servicing. On the furnace end of the bridge there is a 10-ton hook which is very useful in general maintenance about the plant, particularly for changing skip cars.

The furnace is designed for possible future operation on high top pressure. We have planned the whole of the gas-cleaning plant to take 25 lb. pressure, so that, if high top pressure is ever used, instead of reducing the pressure by some sort of restriction, the gas will pass through a very simple turbine, which will thus recover a large proportion of the blowing power and at the same time will cool the gas, with consequent reduction in moisture content, giving a better gas for use in stoves, boilers, and coke ovens.

The water-cooling system is also rather unorthodox. The water at Shotton, from the Dee estuary, although plentiful, has a very variable salt content. The cooling, both on the blast-furnace and on the steel furnaces, was therefore put on a closed system, using heat exchangers, and utilizing the estuary water as a cooling medium.

For the gas washer, Dee estuary water had to be used. Salt water was undesirable, and so a reservoir was built in which sufficient water with a minimum salt content could be stored in a couple of hours to supply the plant during the remainder of the tide cycle.

This water is also used for make-up on the power station boilers, though not directly ; it is deflected again for about 10 min. during the period of minimum salt content into make-up tanks. It is then treated, after fine filtering, and is used as the feed water for the evaporators on the main power plant and as direct feed for the waste-heat boilers on the steel plant.

The sinter plant should be working in a few months time. It has been considerably altered from the original conception, in the light of subsequent experience elsewhere. The main alterations have been in the handling of sinter fines and in the arrangements for cooling the sinter. As the plant was originally designed, the sinter fines from the end of the machine were discharged into a bin of about 50 tons capacity, from which it was fed on to the main feed belt. Experience at other works indicated that this was wrong. The fines must be taken out of the system and stored ; they can then be used as an independent raw material. The fines will now go into storage bunkers of about 300 tons capacity for each strand (*i.e.*, 600 tons in all). The other alteration was made to the sinter cooler, originally of the 'Fontana' design. The centre part has been converted into a big windbox, in which air from four 50,000-cu.ft./min. air fans is discharged. The inside plates of the peripheral hopper have been fitted with discharge louvres.

Mr. **A. Walker** (John Summers and Sons, Ltd.), in his introduction, said : The plant was designed to work on a prepared burden of imported ore and sinter, but owing to the difficulty of getting adequate supplies of imported ore it was found necessary to include in the burden about 30% of Northamptonshire ore. The crushing plant was completed before the furnace was blown in, but owing to the large amount of Northamptonshire ore to be handled it was felt that to keep the furnace charged the secondary crusher should be by-passed. The sinter plant was far from completion, and as there was no means of disposing of the fines, they were charged into the furnace with the lump. The burden therefore consisted of run-of-mine ore broken to 6 in.

During the blowing-in period, the gas plant, the 2 million cu. ft. gas holder, and about 4000 ft. of tubing had to be purged before gas was admitted to the stoves. It was estimated that this could be done in 10 hr.; the three stoves therefore had to contain sufficient heat to last at least 12 hr. Before the furnace was blown in, it was found that coal and wood fires in the stoves would not give the heat required and, as a small quantity of coke-oven gas was available, it also was used to heat the stoves. Filling the furnace took four days, and during this period adjustments were made to the filling equipment, and steps were taken to reduce spillage.

The furnace was lighted at 7.40 A.M. on 27th February, 1953, and at 8.20 A.M. blast was put on the furnace at the rate of 20,000 cu. ft./min. At 11 A.M., the isolation valve was opened, and gas was put through the washer and precipitators.

The whole system, of course, had been purged with steam for 5 hr. before gas was brought down. Immediately before the gas was turned into the tube leading to the boilers, it was noticed that the boiler tubing had opened at one of the joints, no doubt owing to the excessive amount of steam used. A repair was quickly effected, but it held up the purging of the mains for 1½ hr. By 5.54 P.M. the whole system had been purged, and 1 million cu. ft. of gas was held in the holder. The stove main was then purged and gas was put on the stoves at 6 P.M., 9¾ hr. after blast-on. From this point the blast and the burden were steadily increased.

After a few weeks of working, the furnace would swing from 1·75% to 0·5% of silicon from cast to cast. The slag during this period contained 22–23% of alumina and 2–3% of magnesia. The furnace could not be taken off blast for a tuyere between casts without filling the blow pipes with slag. Even with full wind on the furnace a sloppy tuyere would gradually get worse and slag and iron would roll down the blow pipe and burn it ; this happened several times. A number of high-sulphur casts were made during this period. It was obvious that some of the trouble was due to the high alumina content in the slag, and steps were taken to reduce it to 17–18%. At the same time it was thought advisable to increase the magnesia from 3%, which it was then running, to 10–11%.

After these alterations had been made, furnace operation became much easier, but the furnace still fluctuated, though not so violently, giving irregular silicon contents in the metal. It appeared that incipient scaffolds were building up on the bosh wall and then coming away, chilling the hearth.

The ore burden since the furnace was blown in consisted of run-of-mine ore broken to 6 in. As more foreign ore was now available, it was possible to reduce the Northamptonshire ore from over 30% to about 15%. With the reduced quantity of Northamptonshire ore going through the ore-handling plant, it was possible to put the secondary crusher into operation and crush all the ore down to 2½ in.

During one weekend the chutes were altered and the secondary crusher was started up. Following this change, there was a definite improvement in the iron. The silicon content varied between 0·5% and 0·8%,

moving very gradually up and down. There were very few sloppy tuyeres and blast could be taken off between casts without slag coming back in the blow pipes. The great disadvantage was the increase in flue dust, which at times rose to 3½ cwt. per ton of pig iron.

Whilst these changes were being made, further trouble arose at the tap hole. In the past it had given no anxiety, as the length was 4–5 ft., and it was unusual to get a fast run. However, the trouble developed to such an extent that the length came down to 6 in. occasionally. The runs were extremely fast, 250 tons being run in 15 min. On one occasion the large cast-house was covered with slag and several times coke was strewn all over the deck. Fortunately, no breakaway at the tap hole was experienced. The clay used to stop the hole was similar to one used by a subsidiary company for several years, where it had given absolute satisfaction, and for this reason it had been selected for use at Shotton.

It was some time before it was suspected that the clay was the source of the trouble, and after trying all other remedies a change in the clay was made. Several clays were tried, and eventually one was selected which gave a regular tap-hole length of 4–5 ft. and a steady run throughout the cast.

During a 28-day period in July, 1953, the burden was a mixture of 84% imported and 16% home ores. The average daily output was 1036 tons with a coke consumption of 1788 lb. The actual wind blown was 68,660 cu.ft./min. at a pressure of 15¼ lb./sq. in. The calculated slag volume was 1400 lb. per ton of iron.

Mr. **F. B. George** (Consett Iron Co., Ltd.) : I should like to congratulate the authors on the clear way in which this paper has been written. It shows the different methods of attack that have to be used for each problem in the industry, as there could not be two more different plants to deal with on the blast-furnace side than Consett and Shotton. Our difficulty at Consett was to put the plant into the existing site while keeping the rest of the plant working, whereas Shotton was a 'green field' site.

In regard to the foundations, differences between the two plants were tremendous. At Consett there were old coal workings, partially worked out, underneath the whole of the site, all of which had to be explored and filled in.

However, the final solutions at both plants seem to be on largely similar lines. In the Consett ore-handling layout, for example, there is no ore tippler. On the Tyne Commissioners' quay there are five kangaroo cranes for unloading the ships into bunkers, from which the ore comes in special wagons to Consett.

So far as operation is concerned, we have now had considerable experience. The first furnace, installed during the war, produced about 1¼ million tons. The coke rate was not exceptional ; with a wartime burden that production was achieved at an average of about 17 cwt./ton. There was also some slight trouble with breakouts, but the furnace carried on for its full life, and the freedom from serious trouble after those breakouts is attributed to the fact that there was a very good bulk of brickwork around the hearth-cooling staves.

A second furnace was then installed ; after its first campaign it was blown out, relined, and restarted in November, 1953. It produced over 1¼ million tons, and would have produced a good deal more, had it not been necessary to put it out in order to have three furnaces available later for future requirements. The overall coke rate of that furnace was about 15 cwt./ton. The present coke rate on the three furnaces is not quite so good, but it is satisfactory, considering the burden now in use.

The third furnace (now No. 1) at Consett was built in 1949 and blown in September, 1950, and the whole plant is now operating very satisfactorily and regularly.

Mr. **Walker:** The slag pits are working very well indeed. The 1¼-cu.yd. shovel is not quite adequate ; a shovel of 2¼ or 2½ cu.yd. would have been better. Experience also suggests that a different type of dumper, of larger capacity, should have been used.

The slag is rather more honeycombed than ladle slag, so that it may be unfit for use as tarmac, although there are other purposes for which it can be used. The Shotton slag is rather less honeycombed than that produced in U.S. slag pits.

From the furnace point of view, this system is ideal. There is no delay in waiting for ladles, and traffic is no trouble. But it is necessary to study the economic side : if the slag is cooled in ladles the product is denser and, being suitable for tarmac, would command a higher price.

The Dorr thickener is 135 ft. dia., and it does clarify the water. At present water from one furnace only is passing through ; eventually the wash water from two furnaces will have to be treated, but there is no reason why the one thickener should not be adequate.

The slurry can be pumped any distance provided that a good enough pump is available, depending on the suspended matter in the slurry. With up to 30–40% of solids, it can be pumped ¾ mile against a head of 50 ft.

On the question of cyanides, we have taken the wash water (the water from the Dorr thickener) and passed it into a huge lagoon which will hold about 3 million gallons of water. But the cyanides have not been reduced to the extent anticipated. The present figure must be reduced. The cyanide content of the wash water varies from hour to hour.

Mr. **C. Hulme** (Steel Company of Wales, Ltd.) : I presume that the slag pits are sprayed with water to get a fairly good rate of cooling. On those unfortunate occasions when iron goes down the slag runner, is there any explosion when iron runs into the pit ?

Has the slag ever overfilled the pit, owing to a breakdown in the shovel, and run out of the end of the pit ?

On the proposed layout for No. 4 blast-furnace at the Steel Company of Wales, owing to the restricted site, the ends of the slag pits are only 50 ft. away from the main coke stock, and there is some concern about whether one day the coke stock might be ignited if anything untoward were to happen on the slag pits.

Mr. **Walker :** Unless care is taken there is a tendency to overfill the slag pit with water. I have seen a plant where pumps have had to be installed to take the water out of the pit. The slag is watered at Shotton at the end of cast for about ½ hr., unless the wind is in the direction which causes the steam to come into the cast-house.

The coke stock would be safe enough 25 yd. away from the slag pit. Water has never come over the end of the pit at Shotton. From the furnace operator's standpoint slag pits are an ideal way of handling slag.

Even when the furnace was really cold, there was no trouble with iron coming over with the ruffing slag in any quantity. There has never been an explosion, and one would be unlikely, because when slag is run into the pit, the pit is dry.

The slag has to travel about 150 ft. into the slag pit, and it was feared that if the furnace became very cold, it would be impossible to get the slag into the pit. Slag spouts were therefore provided about 20 ft. from the furnace. The furnace has been cold more than once, but these temporary spouts have never been used. The slag has always run the 150 ft. into the pit.

Mr. **J. L. Daniel** (Stewarts and Lloyds, Ltd.) : The figure for the bearing surface of the sand of 4 tons/sq. ft.

seems rather high. I should think there would be no difficulty in putting furnace foundations on such land.

Why are there two sources of power to operate the small bell, from the cold blast and from the compressed-air system, respectively ? Why should the compressed-air systems for the general operating gear not be used ?

It is stated on p. 319 ; " There is a centralized lubrication system for the mechanical equipment on the furnace top, a separate automatic lubrication system being provided for the distributor seal." How does the distributor seal work and why are two systems of lubrication required ?

What diameter pipes are used for conveying the slurry?

Mr. **Jones:** The figure of 4 tons/sq. ft. for this sand is quite correct. The River Dee estuary sand is some of the finest and most granular sand in the world, and it is the shape of the grain rather than the sand itself which affects the bearing capacity. The finest sand is near the works, and the coarse sand is near the estuary.

The bells are, in fact, operated on the compressed-air system, although they should not be. Cold blast is much cheaper than compressed air. A connection was installed from the main 100-lb./sq. in. compressed-air system to operate the bells two or three times if the cold blast was not available, but to operate bells on compressed air which has been compressed to 100 lb. and then reduce it to 17 lb. is wasteful.

Two systems of lubrication were fitted because the amount of grease required for the gas seal was just enough to keep one system fully occupied. A single system might have been used, but it was thought to be advisable to have one system on the seal and one on the jets and other equipment.

Mr. **Walker:** We were reluctant to pump slurry at Consett, and so it was put into tanks, taken up the slag bank, and run on the slag. Experience has shown that the slurry can be pumped ½ mile, even with 30% solids.

If the slurry pump is stopped, however, the pipeline must be flushed with clean water to prevent it from being choked. One works puts 750 lb. pressure water into the pipeline to clean it, but 100 lb. water is sufficient. The ideal slurry-pipe diameter is 4 in.

Mr. **F. C. Doherty** (Stewarts and Lloyds Ltd.) : What is the means of disposal at Shotton of the sludge from the thickener filter press, and also of the blast-furnace flue dust generally? No doubt some of this material goes to the sinter plant, but is there a process for mixing the remainder of the flue dust with the incoming ore? At Corby, flue dust is fed to the wing-tripper conveyor belts at the ore-bedding plant. It is thus thoroughly mixed with ore and ore screening is thereby facilitated.

Mr. **Jones :** The transfer cars are electrically driven directly from collectors. They all work from the bins on the west end of the high line. There is no case for putting in Diesel engines and generators.

We intend to use the slurry and flue dust on the sinter plant.

It is hoped to use 100% foreign ores. If the supply of foreign ores can be maintained, there is no case for a bedding plant. Provision has been made in the layout so that if home ore has to be used, a bedding plant can be installed.

Mr. **Daniel:** The authors have stated that there was difficulty in secondary crushing of Northants ore. I see that cone-type crushers are used. What were the difficulties? The only difficulties experienced at Corby are due to the plastic nature of Northants fine ore during a wet season.

Mr. **Walker:** The crusher became blocked using Northants ores and there were several stoppages. However, when the plant was started up 50% of home ore had to be used, and it was impossible to pass the quantity of ore needed for the blast-furnace through the plant. The screens became blinded, and there was even trouble with the roll crusher because the ore had to be processed at such a fast rate. Our chief trouble with the cone-type crusher was with the soft ore : the fines got through and choked it up. Once this type of crusher is choked, it is difficult to clear and a great deal of time is lost.

About 5000–6000 tons of flue dust have already been produced ; this has been stocked, and there should be no difficulty in getting it through the sinter plant.

The slurry comes off the disc filter and drops on to the mixed-material belt on top of the mixture. Even if it contains 24–26% of moisture it is handled quite easily.

Mr. **M. D. J. Brisby** (B.I.S.R.A.) : I was very interested to hear that both Mr. Jones and Mr. George have chosen the self-discharge type of wagon. The question of wagon discharge has always been controversial and many feel that tippler discharge is preferable, particularly where home ores are used. The solutions adopted by Mr. Jones and Mr. George are the best, because both their works will operate primarily with imported ores, which are reasonably dry and free-running.

The alignment of the ore bridge is remarkably good. If it can be shown that this is due to the design of the carriages, I suggest that this design and its advantages should be made more generally known.

Mr. **R. F. A. Turner** (Staveley Iron and Chemical Company, Ltd.) : Mr. Walker had at the outset to put a large amount of home ore through the plant, although it was not designed for this. The screening plant consists of double-decked vibrating screens, preceded by a two-roll grooved screen for scalping purposes.

A grooved-roll screen has been operated before for screening home ore, with all rolls grooved circumferentially, but this has not been the success that had been hoped. At Shotton one roll is grooved circumferentially and the other longitudinally ; I should like to hear of the experience in operating this. I appreciate that it is only doing a scalping job, but the authors' experience should be valuable in regard to the problem as a whole.

It would seem probable that the longitudinal grooves would get filled with material and become completely caked. Is any form of comb applied to the underside of the circumferentially grooved roll?

Mr. **Walker:** A comb is used on the grooved roll which keeps it reasonably clean. There is little difficulty with this type of roll on soft ores, but with hard ores there has very often been trouble—in fact, we have trouble now. The rolls stall when pieces of hard ore get in the grooves and are held there.

The sinter plant has not yet started, but we have had experience of various ores likely to be used, and with the existing screening arrangement there should be no trouble. Certain features, such as double-deck screens, have had to be installed, although we do not like them. A full report will be given when the plant is working.

Mr. **R. A. Lake** (Stewarts and Lloyds Ltd.): Some years ago I had experience of an electric overhead travelling crane, with admittedly a poor wheel-base/span ratio, which was supplied originally without a cross-shaft but with a separate long-travel motor for each end carriage. The motors operated from ganged controllers and, according to Mr. Jones's theory, the absence of a cross-shaft should have given freedom from cross-winding troubles. The reverse proved to be the case, and cross-winding was only brought under control by installing a cross-shaft geared to the driving wheels on each end carriage.

I admire the way Mr. Jones obtains more than 50% adhesion with only half the end-carriage wheels driven, but neither that nor the independent driving of each end

necessarily represents the complete explanation of why his ore bridge does not cross-wind. Is a device provided which enables the operator to long-travel one end carriage alone, and so to re-align the bridge?

Mr. **Jones:** Whether the theory is right or not, the bridge does not cross-wind, but keeps square. I do not know whether an ordinary overhead crane with a motor at each end can be fairly compared with an ore bridge. Whether the theory is right or not, however, I am sure it is wrong to drive two wheels from one motor.

Mr. **G. W. Grossmith** (Strachan and Henshaw Ltd.): There is no device on the bridge whereby the driver can control one leg independently of the other or correct misalignment. The two legs are separately driven, but the reason why the bridge travels without loss of rectangularity is that the two drives are immediately responsive to, and automatically counteract, any tendency towards misalignment.

Mr. **Jones:** The load per foot of track on our hopper wagons is no greater than would be obtained with an ordinary wheelbox wagon, but there is a great advantage in the speed of unloading. A 1000-ton train can be dealt with from " in siding full " to " in siding empty " in 1 hr. That would not be possible using tipplers and ordinary wagons. To keep the shuttle service going, the big wagon, the hopper bottom, and the ore bench are cheaper than an equivalent number of box wagons working through a tippler. There is also the problem of storing these wagons when ships are not available, which would be greater if the numbers were larger.

Mr. **Brisby:** The question of wagon discharge and sticky ores was examined in some detail in connection with a project on imported ore handling carried out on behalf of the British Iron and Steel Federation.

There must be a clear distinction between home ores and imported ores. Where home ores are concerned, tippling is definitely preferable, and the best tippler today is the new 27-ton iron-ore tippler wagon. This wagon is the outcome of joint co-operation between the Federation and British Railways; it has no doors, is of welded construction, and costs only about £400.

Where imported ores are used, preference should be given to bottom-discharging wagons, as bottom discharge is definitely faster with good free-running ores. The fastest tippler I know will discharge a wagon in about 80 sec., and there are a number of tipplers which take about 2½ min. per wagon. Both these figures compare unfavourably with bottom discharge of imported ores.

The question of the best size of wagon to use for iron ore has been the subject of much discussion during the last few years. The maximum payload which can be carried on four wheels in the U.K. today is 27 tons; above this, wagons must be fitted with bogies. The payload can then go up to about 60 tons on certain routes.

As far as train length and load per foot run of track are concerned there is little to choose between the 27-ton four-wheel wagon and the 60-ton eight-wheel wagon. Despite its much greater cost (about £2000) the advantages of the 60-ton wagon are felt if a regular short shuttle service is worked between the port of discharge and the works, as at Shotton and Consett, where these wagons are operated over 18–20 miles, in conjunction with special loading and discharging facilities.

Mr. **W. M. Larke** (Stewarts and Lloyds, Ltd.): We have had two 12-ton cranes in operation for eight years. Their span is 115 ft. and their rates of acceleration are very high. They are independently driven, with no cross-shaft. Practically no trouble with cross-winding has ever been experienced, in spite of the fact that they work very hard 24 hr. a day. The two causes are maladjustment of the brake and a slippery rail on one side.

Mr. **Jones:** There are no taper treads. Every crane that we have built recently has been on parallel treads, with no track wheels geared together.

Mr. **G. Hookham** (John Miles and Partners (London), Ltd.): The S.A. John Cockerill plant, discussed at the morning session, has a tippler designed to tipple large bogie wagons with a gross load of 80 tons at the rate of 20 wagons per hour. The net load of ore is 50 tons, so that a throughput rate of 1000 tons/hr. is possible. As many as 40 wagons per hour are regularly handled by tipplers in the U.K., and there should therefore be no difficulty in achieving a 2000-tons/hr. throughput rate.

Mr. **Jones:** There are difficulties in handling wagons at the necessary rate. The hopper-bottomed wagons, although more costly, were for our particular conditions more economical than the tippler wagons. It was also more economical to buy the wagons, in spite of their high cost, because the saving in wagons more than paid the interest charges. By buying special wagons we could at least have a reasonable assurance that they would be reserved for our own job. The calculations made at the time were in favour of the 50-ton hopper-bottomed wagons, rather than the 27-ton wagons.

Mr. **G. K. Tatterson** (John Summers and Sons, Ltd.): We have a standard wagon in which, at the maximum, we hope that, on the new permitted gross laden weight, we shall be able to obtain a 55-ton payload per wagon. The crane drivers at Bidston dock are presented with the same type of wagon all the time, instead of a miscellaneous collection of British Railways wagons, some at least 50 years old. It is common to see 12-tonners, 15-tonners, 20-tonners, and 24-tonners, all in one lot of wagons presented to the crane driver. This is a distinct advantage in favour of special wagons, and has gained the greatest praise from those who have to load them.

We shall eventually be able to get a higher average load in our wagons. Figures of the actual payloads achieved show a 10–15% deficiency on the normal maximum loading of the wagons.

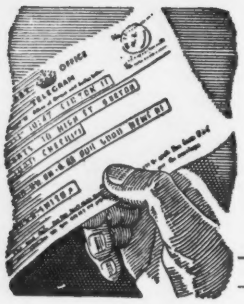
These wagons are so made that the operating doors are all along one side of the wagons, thus helping the operators in the unloading. The standard Charles Roberts drop-door used is very efficient. The mixture of doors on B.R. wagons are very difficult to open.

Ten of these big wagons can be accommodated on the bench as one engine load. At present the biggest engine-load that an engine will bring from Bidston is 14 wagons; 20 wagons, representing two trips on to the ore bench, would be more satisfactory.

Major **W. R. Brown** (Ashmore, Benson, Pease and Co.): The paper, as published, is little more than a descriptive specification, and so I hope we can persuade the authors, after their experience with the installation at work, to recount what they now think of the general conception and main principles that lie behind this very impressive plant. An eminent authority recently declared himself to be in favour of a moderate number of medium-sized furnaces rather than a minimum number of large furnaces. In support of this, it is argued that continuity in supply of hot metal and gas is better assured; that the loss of production when a furnace is relined is less severe; and that costs are not greatly affected, as the acknowledged saving in labour is only a small fraction of the total when raw materials are taken into account.

Shotton has followed the trend towards large furnaces, but the concept extends to only two units. Have the authors any misgivings about putting all their eggs into two baskets? Or are there advantages that outweigh the potential disadvantages?

Mr. **Jones:** The question of the number of blast-furnaces was given considerable thought in the early stages, but the furnace sizes were decided before starting.



# N E W S

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

## THE IRON AND STEEL INSTITUTE

### The Secretary

#### Award of Swedish Honour

During the Institute's Special Meeting in Sweden the President of Jernkontoret, Mr. Evert Wijkander, announced that His Majesty The King of Sweden had graciously conferred upon Mr. Kenneth Headlam-Morley, Secretary of The Iron and Steel Institute, the insignia of Chevalier (Riddare) of the Order of Vasa in recognition of his contribution within the Institute's field of action towards the promotion of friendly relations between the British and Swedish Iron and Steel Industries.

The decoration was handed to Mr. Headlam-Morley at a private dinner party given by Jernkontoret in Stockholm on 10th June, 1954.

### Visit to Finland

A representative party of Members of the Institute visited Finland by personal invitation as guests of Mr. Berndt Grönblom, Chairman and Managing Director of O. Y. Vuoksenniska AB, between 19th and 26th June, 1954. The party, which numbered about 50 persons, included the President and some Members of Council, the Secretary, and Members from France, the Netherlands, and Sweden, as well as Members from Great Britain and their ladies. A short account of the visit will be published in the October issue of the *Journal*.

### Autumn General Meeting, 1954

The dates of the **Autumn General Meeting** this year have been changed. The revised dates are **Wednesday and Thursday, 17th and 18th November, 1954** (instead of 24th and 25th November, as previously announced).

The meeting will be held at the offices of the Institute at 4 Grosvenor Gardens, London, S.W.1.

### Annual General Meeting, 1955

The **Annual General Meeting** next year will be held at the offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on **Wednesday and Thursday, 27th and 28th April, 1955.**

The dinner for Members will be held at Grosvenor House, Park Lane, London, W.1, on Wednesday, 27th April, 1955.

### Forgemasters

The Comité de la Grosse Forge Française has accepted an invitation from The Iron and Steel Institute and the National Forgemasters Association to hold a joint meeting in London in October, 1954.

Technical sessions, which are open to all Members of the three organizations, will be held at the offices of the Institute at 4 Grosvenor Gardens, London, S.W.1, during the morning and afternoon of **Tuesday, 12th October,** and the morning of **Wednesday, 13th October, 1954.** The programmme will be announced later. The British Forgemasters propose to entertain their French colleagues and to arrange for them to visit certain works by personal invitations.

### Symposium on Powder Metallurgy, 1954

The Iron and Steel Institute is organizing a **Symposium on Powder Metallurgy,** to be held in London on **Wednesday and Thursday, 1st and 2nd December, 1954.** Preliminary details were given in the May issue of the *Journal*. About fifty papers will be presented, divided into four groups : The Manufacture, Properties, and Testing of Powders ; The Principles and Control of Compacting and Sintering ; The Manufacture and Properties of Structural Engineering Components ; Powder Metallurgy of High Melting-Point Materials. Advance copies will be available before the meeting ; full details and application forms will be issued later.

As previously announced, a small exhibition of powder-metallurgy components will be organized; the purpose will be to show, not so much ordinary parts in normal production, but specimens with special characteristics or examples of the application of powder metallurgy to problems difficult of solution by other methods. Any company in the U.K. wishing to display components in this exhibition is invited to submit a list of proposed specimens, with brief details of their particular points of interest, to the Secretary, The Iron and Steel Institute, 4 Grosvenor Gardens, London, S.W.1. This will enable the Organizing Committee to select items that may be built up into an exhibition illustrating the present state of development of the production of powder-metallurgy components in the U.K. The Committee reserves the right to accept or reject exhibits at its discretion.

### Iron and Steel Institute Prize, 1954

The Iron and Steel Institute Prize at Sheffield University for 1954 has been awarded to Mr. Geoffrey Greetham, B.Met. (Hons.).

## NEWS OF MEMBERS

**Dr. Howard Biers**

Mr. Howard Biers, Consulting Engineer, was awarded the degree of Dr. mont. (Doctor of Mining and Metallurgical Sciences) of the University of Mining and Metallurgy, Leoben, on 3rd June, 1954. In May this year, Dr. Biers was formally elected President of the International Institute of Welding during the Institute's Annual Assembly, held in Florence.

▶ Mr. G. G. ABRAHAM has left the Wellman Smith Owen Engineering Corporation Ltd. to join General Refractories Ltd., Middlesbrough.
▶ Mr. S. C. ANTHONY has obtained an Insignia Award in Technology of the City and Guilds of London Institute.
▶ Mr. E. I. BRIMELOW has taken up an appointment at the National Physical Laboratory as liaison officer between the Laboratory and industry.
▶ Mr. G. W. BROWN has left Douglas (Kingswood) Ltd. to become Chief Chemist to Newman, Hender and Co., Ltd., Woodchester.
▶ Mr. W. F. CARTWRIGHT, Director and General Manager of the Steel Division of the Steel Company of Wales Ltd., has been appointed Assistant Managing Director of the Company.
▶ Mr. W. L. FINLAY of Rem-Cru Titanium Inc. has been awarded the degree of Ph.D.
▶ Mr. C. C. HANSON has left High Grade Steels Ltd. to join the Central Research Laboratories of Radiation Ltd. as a Research Metallurgist.
▶ Mr. W. E. HARVEY has left John A. Roebling's and Sons Corp., Trenton, U.S.A., to join Henry Disston and Sons Inc., Philadelphia, as Director of Metallurgy and Inspection.
▶ Mr. J. MORAN has taken up the appointment of Works Manager to W. T. Flatter Ltd., Sheffield.
▶ Mr. J. A. NAISMITH has been awarded the degree of Ph.D. of the University of London.
▶ Mr. M. C. REGAN has been awarded the degree of B.Sc. of the University of Durham.
▶ Mr. P. ROBERTS has left David Brown-Jackson Ltd. to become a Junior Technical Assistant in the Metallurgical Research Department of Metropolitan-Vickers Electrical Co., Ltd.

## Birthday Honours

Mr. GEOFFREY SHAW, of W. Shaw and Co., Ltd., has been awarded the C.B.E.

## Obituary

Sir GEOFFREY DUKE BURTON, on 2nd July, 1954.
Mr. G. F. CORBETT, of Tickhill, near Doncaster, on 28th January, 1954.
Mr. J. W. STEWART of Gartcosh, near Glasgow, on 21st October, 1953.

## Verein deutscher Eisenhüttenleute

Dr. K. THOMAS has been appointed a Director of Verein deutscher Eisenhüttenleute in place of Mr. K. P. Harten.

## CONTRIBUTORS TO THE JOURNAL

**B. B. Hundy, B.Sc., Ph.D., A.I.M.**—Senior Investigator in the Metal Working Laboratories of the British Iron and Steel Research Association at Sheffield.

Dr. Hundy was born in Birmingham in 1928. He was educated at King Edward School, Birmingham, and at Birmingham University, graduating with 1st Class Honours in Industrial Metallurgy in 1948. He spent a further two years in the Department of Industrial Metallurgy at the University, and in 1950 he was awarded the degree of Ph.D. for work on the inhomogeneous deformation of metals. He then spent a year in the U.S.A. as a Research Fellow in the Metallurgy Department of the Massachusetts Institute of Technology. Returning to the U.K., he joined the Mechanical Working Division of B.I.S.R.A., and has since been engaged on metallurgical problems associated with the working of metals.

B. B. Hundy

A. H. Sully

**A. H. Sully, M.Sc., Ph.D., F.Inst.P., F.I.M.**—Principal Physicist at the Fulmer Research Institute.

Dr. Sully received his technical education at the University College of North Wales, graduating with 1st Class Honours in Physics in 1935. A year later he was awarded the degree of M.Sc., and in 1939 he received the degree of Ph.D. for research, with Professor E. A. Owen, on the equilibrium and non-equilibrium states in the iron–nickel system. In the same year he joined the Development and Research Laboratory of the Mond Nickel Co., Ltd., in Birmingham, and was appointed Head of the Physics Section in 1943. During this period he was closely associated with the development of the Nimonic series of alloys. He took up his present appointment in 1946, and is in charge of the Physics and Metallurgy Departments of the Fulmer Research Institute.

The author of numerous scientific papers, Dr. Sully has also written two books, "*Metallic Creep*" and "*Chromium.*"

## IRON AND STEEL ENGINEERS GROUP

The **Twenty-Sixth Meeting** of the Iron and Steel Engineers Group will be held in **Newcastle-on-Tyne** from **Monday to Thursday, 13th to 16th September, 1954,** by invitation of Mr. H. Boot, Managing Director of the Consett Iron Co., Ltd. A technical session on Tuesday, 14th September, at the Royal Station Hotel, Newcastle-on-Tyne, will be devoted to the presentation and discussion of papers on developments at the Consett works, given by various members of the Company. The detailed programme is as follows:

10.0–11.0 A.M.—Discussion on:
"*The Engineering Aspects of the Duplex Steelmaking Process,*" by W. E. Ward
11.0 A.M.–12.30 P.M.—Joint discussion on:
"*The Slabbing/Blooming and Continuous Billet Mill Installations and their Layout,*" by A. Marshall
"*Operational Experience with the Slabbing/Blooming and Continuous Billet Mills,*" by A. Henderson
12.30–2.0 P.M.—Buffet Lunch
2.0–3.30 P.M.—Joint discussion on:
"*Electrical Developments at Consett,*" by T. Coxon
"*Some Aspects of Electrical Maintenance,*" by R. Mathieson
"*Industrial Power Station Operation,*" by T. F. Hutchinson
3.30–4.30 P.M.—Discussion on:
"*Description of and Experiences with the New Ore Handling Plant,*" by S. C. Pearson.

The following days will be devoted to visits to works at Consett and Jarrow, and to the ore discharge terminal at Tyne Dock.

The papers and a report of the discussions will be published later in the *Journal.*

## INSTITUTE OF METALS

### Annual Autumn Meeting, 1954

The Autumn Meeting of the Institute of Metals will be held this year in Switzerland, by invitation of the Société Suisse des Constructeurs de Machines and the Association Suisse pour l'Essai des Matériaux. The meeting will open in Zürich on 6th September, and will move to Montreux from 11th to 14th September. Three technical sessions will be held in Zürich: On 6th September two papers on Grain Refinement will be presented for discussion; on 8th September two papers on Extrusion Direction and Staining of Clad Aluminium Alloy Sheets respectively will be discussed; and on 10th September eight papers on the Constitution of Titanium Alloys will be presented. The programme will include works visits in Zürich, Winterthur, Neuhausen, Schaffhausen, and surrounding districts.

## EDUCATION

### Research Fellowship

Applications are invited for the W. J. Rees Research Fellowship, tenable in the Department of Refractory Materials in the Faculty of Metallurgy of the University of Sheffield. The object of the Fellowship is to advance knowledge in the field of refractory materials; candidates should already have some research experience, but not necessarily in this field. Normal tenure will be five years, but the appointment will be for two years in the first instance, and thereafter will be renewable annually. The appointment carries a stipend of £750 p.a. for the first year, rising by annual increments of £50 to £950 p.a., together with superannuation provision under the F.S.S.U. A higher stipend may be paid to an exceptional candidate. Applications (3 copies) including the names and addresses of referees and, if desired, copies of testimonials, should reach the Registrar, from whom further particulars may be obtained, not later than 15th September, 1954.

Applications are also invited for the C. H. Desch Research Fellowship, tenable in the Department of Metallurgy. The object of the Fellowship is to advance knowledge in the field of ferrous metallurgy ; candidates should already have some research experience, but not necessarily in this field. The details of tenure and stipend are as given above for the W. J. Rees Fellowship. Applications (3 copies) including the names and addresses of referees and, if desired, copies of testimonials, should reach the Registrar, from whom further particulars may be obtained, not later than 30th September, 1954.

## NEWS OF SCIENCE AND INDUSTRY

### Conference on Microanalysis

A Conference on Microanalysis will be held by the Max-Planck Institut für Eisenforschung in Düsseldorf, on 1st October, 1954. Five papers will be presented for discussion: "*Microanalytical Determination and Separation of Trace Elements in Iron*," by Dr. Malissa (Düsseldorf); "*Spectrographic Determination of Trace Elements Without Previous Separation*," by Dr. W. Koch (Düsseldorf); "*Procedure for the Concentration and Spectrographic Determination of Trace Elements*," by Dr. H. Specker (Dortmund); "*Determination of Boron in Steel*," by Mr. H. G. Short (N.P.L.); "*Trace Analysis using Radioactive Isotopes*," by Dr. W. Herr (Mainz).

### Sulphur Removal and Recovery from Fuels

The Institute of Fuel has arranged for a conference to be held on 6th–7th October, 1954, to cover a Special Study of Sulphur Removal and Recovery from Fuels. The conference will be held at the Institution of Mechanical Engineers, Birdcage Walk, London, S.W.1. Programmes of the technical sessions and further details may be obtained from the Secretary, The Institute of Fuel, 18 Devonshire Street, Portland Place, London, W.1.

### British Steel Castings Research Association

The first Annual General Meeting of the British Steel Castings Research Association was held in York on 13th July, 1954. After the meeting, a series of demonstrations were given of the Association's activities during the past year by means of photographs and working models.

### Operation Seraphim

The £14-million ironworks extension project at the Appleby-Frodingham Steel Co., Scunthorpe, was completed on 29th July, 1954, when Sir Archibald Forbes, Chairman of the Iron and Steel Board, started up the sinter plant and lit the 'Queen Victoria' blast-furnace. 'Queen Victoria' is the largest blast-furnace in Europe, and, together with her sister 'Queen Anne,' is expected to boost the works output of pig iron by more than 600,000 tons per year. Many leading industrialists and representatives from research organizations and associated industries were present at the ceremony.

## CORRIGENDUM

### Nature of Ironstone Sinter

The following correction should be made to the paper by E. Maud McBriar, W. Johnson, K. W. Andrews, and W. Davies (*J. Iron Steel Inst.*, 1954, vol. 177, July, pp. 316–323): On p. 323, 12 lines below the heading "X-Ray Examination," "FeO, %" should be replaced by "$Fe_3O_4$, %."

## DIARY

**1st–8th Sept.**—BRITISH ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE—Annual Meeting—Oxford.

**2nd–18th Sept.**—Scottish Industries Exhibition—Glasgow.

**6th–14th Sept.**—INSTITUTE OF METALS—Autumn Meeting—Zürich and Montreux, Switzerland.

**10th Sept.**—WEST OF SCOTLAND IRON AND STEEL INSTITUTE—Conference on Open-Hearth Flames and Output—39 Elmbank Crescent, Glasgow, 10.0 A.M.

**13th–16th Sept.**—IRON AND STEEL ENGINEERS GROUP—Twenty-Sixth Meeting—Newcastle-on-Tyne.

**22nd Sept.**—NORTH WALES METALLURGICAL SOCIETY—"*The Cold Working of Metals*," by J. G. Wistreich—County Primary School, Plymouth Street, Shotton, 7.15 P.M.

**24th–27th Sept.**—ASSOCIATION OF SPECIAL LIBRARIES AND INFORMATION BUREAUX—Annual Conference—Church House, Westminster, London, S.W.1.

## TRANSLATION SERVICE

(The previous announcement was made in the August, 1954, issue of the *Journal*, p. 457).

TRANSLATION AVAILABLE

No. 491 (German). "The Lining of Mixers": (*A*) K. MAYER, F. GAREIS, S. KIENOW, H. KNÜPPEL, and G. TRÖMEL: "The Lining of an 800-Ton Mixer with Dolomite Bricks." (*Stahl und Eisen*, 1953, vol. 73, Nov. 5, pp. 1457–1462). (*B*) K. MAYER and H. KNÜPPEL: "The Lining of an 800-Ton Mixer with Chemically Bonded Magnesite Bricks." (*Stahl und Eisen*, 1953, vol. 73, Nov. 5, pp. 1463–1464).

# ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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## ORES—MINING AND TREATMENT

**Consett Iron Company Limited: Ore Unloading, Stocking and Reclaiming.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 45–48). Details are given of the ore-unloading and stocking bridges, conveyors and screening plant installed at the Consett works. The plant is designed to handle various types of iron ore and limestone, at a normal running throughput of 500 tons/hr.—G. F.

**Consett Iron Company Limited: Sinter and Ore Preparation.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 49). A brief outline is given of the 14-windbox Dwight-Lloyd sinter plant being installed at the Consett Iron Co., Ltd.—G. F.

**Saleable Iron Ore Gleaned from Unmined Remnants.** E. T. Binger. (*Eng. Min. J.*, 1954, **155,** Jan., 89–91). The Pacific Isle Mining Co. operates on the Mesabi Range by treating crude ores and wastes left behind by previous concerns ; it uses small-scale, modern ore-beneficiation plants, *e.g.*, screening, washing, rake-classifying, heavy-media, jigging, and Humphreys spirals.—K. E. J.

**Differential Grinding in Cyclone Shown by Screen Tests.** S. E. Erickson. (*Eng. Min. J.*, 1954, **155,** Jan., 95, 168). In the course of batch cyclone test work to develop a concentration process, it was shown that a differential grinding effect was produced when Mesabi intermediate ore was passed through a 6-in. cyclone, the ore being higher in grade after the tests. Whether or not this process would compete with abrasion milling cannot yet be stated.—K. E. J.

**Starches and Starch Products as Depressants in Amine Flotation of Iron Ore.** C. S. Chang, S. R. B. Cooke, and R. O. Huch. (*Min. Eng.*, 1953, **5,** Dec., 1282–1286). To effect satisfactory separations, depressants are needed when using laurylamine derivatives for flotation. Six starch products have been assessed for their effectiveness as depressants, pearl starch giving best results. For additions of 0·26 lb. of laurylamine acetate per ton, the optimum *p*H is 6–8.—K. E. J.

**Nodulizing Iron Ores and Concentrates at Extaca.** R. L. Bennett, R. E. Hagen, and M. V. Mielke. (*Min. Eng.*, 1954, **6,** Jan., 32–28). Details are given of experimental runs on the 10ft. 6 in. diameter (interior), 350 ft. long nodulizing kiln of U.S. Steel Corp. Great attention is paid to temperature control in the short nodulizing zone, and a cooler is provided. The addition of fine limestone (up to 10%) reduces nodulizing temperature and ring formation. The major principles for successful operation are constant feed rates, kiln speed, and oxygen content of the stack gas.—K. E. J.

**Application of Hydraulic Cyclones for the Concentration of Lean Ores.** P. H. Fahlström. (*Jernkontorets Ann.*, 1954, **138,** (1), 1–16). [In Swedish]. After briefly outlining cyclone theory and separation efficiency, the author gives details of Scandinavian research into hydraulic cyclones as classifiers, practical experience at the Stripa plant with hematite slurry being reported. When employing a unit having a separation limit of 25 microns, the consumption of reagent per ton of material treated by flotation was almost halved, and the proportion of concentrate increased greatly. Assuming 20% solids in the feed, typical operating costs for cyclone separation are 5 öre/ton, of which 2·5 öre are for power consumption.

**Clarifying Waste Water from Concentration Plants by Flocculation with Glue.** V. Öhman. (*Jernkontorets Ann.*, 1954, **138,** (2), 97–112). [In Swedish]. The theory of sedimentation and results of practical tests on flocculation at eight Swedish plants, using either 'once-through' or reclaimed water, are described. It was observed that process costs depended largely on glue quality and the effect of adding aluminium sulphate or calcium hydroxide to disperse the electrical charges in the glue and slurry. Actual costs ranged from 0·8 to 2 öre/cu. m. of waste water.—G. G. K.

**Studies on the Roasting of Kamaishi Iron Ore.** K. Kato. (*Tetsu to Hagane*, 1950, **36,** June, 242–245). [In Japanese]. Plant trials determined the correct proportions of coke breeze, size of ore, and roasting temperature. Up to 50% desulphurization was achieved.—K. E. J.

**Sinter-Plant Operation at Appleby-Frodingham.** N. D. Macdonald. (*J. Iron Steel Inst.*, 1954, **178,** Sept., 51–60). [This issue].

**Microstructures Observed in the Sinters of the Monlevade Works.** J. Wscieklica. (*Bol. Min. Industr.*, 1953, **9,** July, 332–343). [In Spanish]. The Monlevade works normally use a semi-self-fluxing sinter produced from Itabirito fines and Jacutinga ore with an addition of granulated blast-furnace slag. Recently, a trial lot of 900 tons of self-fluxing sinter was made and granulated steelworks slag was used instead of blast-furnace slag. The author describes the preparation of the sinter samples for micro-examination. The relationships between the quality of the sinter and its microstructure and the 'metallic' bond between the particles of sintered ore are discussed. In order to obtain a strong, highly oxidized sinter from hematite, the hematite must be reduced (at least on the surface) to $Fe_3O_4$ in the combustion zone, and subsequently reoxidized to $Fe_2O_3$.—R. S.

**Adjustment of Rotary Kiln Rollers.** H. H. Wight. (*Mech. World*, 1953, **133,** Nov., 506–508). The long shells of rotary cement kilns and pelletizing furnaces are supported on rollers which are skewed to overcome the end thrust caused by the

inclination of the kiln. An original geometrical analysis of the skewed roller is presented together with notes of results obtained in kiln setting.—D. H.

## FUEL—PREPARATION, PROPERTIES, AND USES

**General Results of the Work of the International Committee Studying Flame Radiation.** M. Michaud. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (7), 1109–1129). The results of work on flame radiation carried out in the 7-in. long combustion chamber at Ijmuiden are reported. In the first period each of the variables, type of liquid fuel, amount of fuel, nature and amount of atomizing agent, and quantity of combustion air was investigated at two levels. Radiation as a function of distance from burner presents a maximum which is 17% less for fuel oil than for pitch–creosote mixtures. Replacing air by steam as an atomizing agent lowers radiation by 11%, whilst increasing the amount of atomizing agent accelerates combustion and lowers radiation at the flame extremity. Five types of burner were next studied and the basic factor was found to be the volume of movement of the jet. Industrial tests on the addition of fuel oil to coke-oven gas were made and no significant increase in radiation was observed beyond 70% fuel oil. Air atomization was twice as effective as mechanical methods.—A. G.

**Principles of Good Combustion.** (*Acero y Energia*, 1953, Dec., 29–31). [In Spanish]. The author discusses principles which must be observed to achieve optimum combustion. He deals with the supply of excess air for solid, pulverized, liquid, and gaseous fuels. The factors of time of contact between reaction agents, necessary turbulence to obtain intimate mixtures of air and fuel, and the temperature factor in combustion are discussed.—R. S.

**Composition Profiles in Pre-Mixed Laminar Flames.** R. Prescott, R. L. Hudson, S. N. Foner, and W. H. Avery. (*J. Chem. Phys.*, 1954, **22,** Jan., 145–146). The authors describe a technique for determining composition profiles through a pre-mixed laminar flame front. By means of a fine fused quartz probe, samples are taken at various distances normal to the flame front using the centre of the luminous zone as a reference surface. These samples are analysed by a rapid-scanning mass spectrometer. Preliminary results from experiments with a propane–air flame are given.—L. E. W.

**Flame Propagation: The Effect of Pressure Variation on Burning Velocities.** Sir Alfred Egerton and A. H. Lefebre. (*Proc. Roy. Soc.*, 1954, **A222,** Mar. 9, 206–223). Burning velocities of mixtures of methane, propane, ethylene, and propylene with air were investigated under constant pressure conditions. The pressure exponent was 0·5 for methane, and approx. 0·3 for the other gases ; richer mixtures are less affected by pressure. Both heat and diffusion (particularly of hydrogen atoms) play a part in flame propagation. (30 references).—K. E. J.

**Combination Characteristics of Fuel Gases.** J. Grumer. (*Proc. Amer. Gas Assoc.*, 1952, 853–856). The author introduces a method of predicting burner performance with exchanged fuel gases and indicates certain applications of it. The method uses the critical limits of a flame's boundary velocity gradient related to the gas-air composition in the burner. Reference is made to work by the Bureau of Mines and Amer. Gas Assoc. concerning blow-off and flash-back for primary and mixed gases.—D. L. C. P.

**Studies on Combustion of Gaseous Fuel.** S. Yagi and K. Saji. (*Annual Report Engineering Res. Inst., Tokyo University*, 1953, Dec., No. 12, 127–130). [In Japanese]. The authors discuss eddy diffusivity of non-isotropic jet flow, specification of flames, and the numerical evaluation of the modified eddy diffusivity for mass transfer in a combustion jet. An approximate equation for the combustion rate in fully turbulent flow is derived and its application shown by an example. The eddy diffusion layer length, a microstructure of turbulent flame, and other considerations concerning the combustion rate coefficient are referred to.—L. E. W.

**How Can a Heat Balance Be Rapidly Drawn Up ?** (*Acero y Energia*, 1953, Dec., 60–62). [In Spanish]. The article explains how to draw up a heat balance and gives two examples, one referring to a steam boiler and one to a producer gas-fired recuperative furnace.—R. S.

**A Theory of Vortex Combustion-Chamber Design.** H. A. Havemann. (*J. Inst. Fuel*, 1953, **26,** Dec., 294–305 ; 1954, **27,** Jan., 25–34). The theory of a vortex combustion chamber for burning heavy fuel oil is developed and expressed in a series of equations. The principles are described and the effect of the main plant and operating variables worked out. The argument is developed to describe methods for the design of vortex chambers. Problems associated with combustion in the cyclone are considered qualitatively. It is concluded that optimum conditions can be realised in the vortex chamber.

**Smoke Abatement in Metallurgical Furnaces.** R. J. Sarjant. (*Smokeless Air*, 1954, **24,** Spring issue, 129–131). The author outlines briefly work carried out in the University of Sheffield during 1952–53 on the problem of smoke emission from low-temperature metallurgical furnaces. A survey of existing practice was undertaken to determine how far the causes were due to economic, sociological, and technical factors. Laboratory experiments are also reported. The author concludes that the smoke problem has two main causes : (1) The use of old-fashioned appliances and out-moded techniques ; and (2) lack of application of existing knowledge through ignorance or apathy.—L. E. W.

**The Effect of Fluid Motion on Heat Transmission. Part II. Determination of the Forced Convection Constant.** D. G. Kapadnis. (*Indian J. Phys.*, 1953, **36,** Nov., 533–540). The author describes a detailed experimental study of the forced convection constant which is shown to have a value of $7 \cdot 56 \times 10^{-5}$, the heat being measured in calories. The constant depends on the physical properties of the fluid, and the value obtained is in fair agreement with that derived theoretically using Nusselt's equation.—L. E. W.

**Second Law Analysis.** E. A. Bruges. (*Engineer*, 1954, **197,** Mar. 5, 341–344). The author discusses a method of analysis based on the Second as well as the First Law of Thermodynamics, which, it is claimed, offers more than the conventional ' heat balance '. The concepts of available and unavailable energy upon which the analysis depends are discussed and an evaluation of irreversibility is given. The author then illustrates the advantages of the analysis using four worked examples for which a conventional heat account is prepared for comparison.—M. D. J. B.

**The Recovery and Use of Rejected (Waste) Heat in Industry.** S. J. Eardley. (*J. Inst. Fuel*, 1954, **27,** Feb., 67–78). The author reviews factors influencing the possibility of waste heat recovery and gives practical and detailed examples of the application in many industries.—D. L. C. P.

**Mathematical Theory of the Flow of a Gas in a Porous Solid and of the Associated Temperature Distributions.** D. R. Bland. (*Proc. Roy. Soc.*, 1954, **A221,** Jan. 7, 1–28). Gas flow is considered in conditions when there is heat exchange with the porous solid. Means of determining the velocity and temperature distributions in a general case are put forward. A simple heat-treatment equation is postulated. Special cases considered explicitly include that of a regenerator with reversal of flow.—K. E. J.

**Consett Iron Company Limited: Coke Oven Plant.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 42–45). The new coke-oven battery at Consett consists of 17 " Wilputte " ovens carbonizing 2725 tons of coal per week. A detailed description is given of the battery, including the oven-heating system, the doors, reversing machine and instruments, coke-oven machines, coke guide, and door extractor.—G. F.

**The Desulphurisation of Coke-Oven Gas.** T. H. Williams. (*Coke Gas*, 1954, **16,** Feb., 61–67). A detailed description is given of the plant recently installed at Stewart and Lloyds Ltd., Corby, for the removal of sulphur from coke-oven gas using the Collin ammonia process. The sulphur compounds are subsequently converted to sulphuric acid by the Chemiebau wet contact process. Details of plant operation and control are given for both processes and the records show that over the past six months the production of sulphuric acid has been sufficient to supply all the requirements of the by-product plant. Approximately 80% of the $H_2S$ can be recovered and the desulphurized coke-oven gas has been found to give better results in other departments of the works.—B. C. W.

**Thermal Conductivity of Coal Tar Pitch.** D. K. H. Briggs and F. Popper. (*Fuel*, 1954, **33,** Apr., 222–229). A description is given of an apparatus for measuring the thermal conductivity of substances having a high viscosity. The results obtained with ten commercial coal tar pitches are given and discussed.—B. G. B.

**A Study of the Precision of the Shatter Test on Coke.** J. B. Gayle and H. S. Auvil. (*U.S. Bur. Mines Rep. Invest.* 4987,

1953, June). The results of a statistical examination of data obtained from shatter tests carried out on cokes are given and suggestions are made for improving the precision of the tests. Appreciable gains in precision can only be obtained by increasing the weight of coke on which the result is based.

**Coke Breakage.** R. T. Hancock. (*Coke Gas*, 1954, **16,** Jan., 31–32). The laws governing the random breaking of a brittle solid are discussed in conjunction with the results of work carried out at Carnegie Institute of Technology on the breaking of coke. In the shatter or drop test the probability of breaking is proportional to the square of the size diameter and the distribution of sizes follows a normal Gaussian distribution except for very small sizes, when it may become log-normal. No correlation could be found between the results of the tumbler or drum test and those of the shatter test.

**Bibliography of Bureau of Mines Investigations of Coal and Its Products, 1945 to 1950.** E. P. Carman, M. Opperman, S. Nishiyama, and L. Raccosin. (*U.S. Bur. Mines Bull.*, 528, 1954).

**Performance of a "Hot Gas" Mechanical Producer.** K. Morris-Ashton. (*Gas World*, 1954, **139,** Jan. 23, 251–254). Results are given of tests carried out on West-type mechanical hot gas producers using different coke gradings. Best results were obtained with high blast rates, a deep ash bed, and a fairly narrow reaction zone. The test with about 30% breeze was highly successful, but channelling often resulted in poor-quality gas and a high sensible heat content. From economic considerations it is concluded that the hot gas producer is more suitable than large producers for medium-sized plant.—B. C. W.

**Experience with Steam-Jacketed Gas Producers for Open-Hearth Furnaces.** H. Wübbenhorst. (*Stahl u. Eisen*, 1954, **74,** Feb. 25, 272–279). Works trials have shown that steam-jacketing of producers reduces the calorific value and sensible heat of the gas only if the amount of steam produced is in excess of that required for feeding the producer. Matching of the steam produced with that required can be achieved by suitable choice of jacket area and volume. When this is done and when coal supply is automatic, the calorific value and temperature of the gas do not fall far short of those from brick-lined producers. The higher through-put, decreased servicing, and the elimination of cross-sectional changes made possible by steam-jacketing can cut gas production costs appreciably.—J. P.

**Some Properties of Gas Mixtures.** A. M. Godridge. (*Brit. Coal Utilisation Res. Assoc. Monthly Bull.*, 1954, **18,** Jan., 1–21). This review surveys the theory, experimental methods, and published literature concerning the specific heats, viscosities, and thermal conductivities of nitrogen, oxygen, hydrogen, carbon monoxide, carbon dioxide, methane, water vapour (steam), and air. (136 references.)—R. A. R.

**The Storage of Gas.** (*Coke Gas*, 1954, **16,** Feb., 68–73). The report is presented of the committee on gas storage set up by the Ministry of Fuel and Power, and the Ministry of Housing and Local Government, to consider gasholder design in relation to the amenities. The economics of gasholder design are discussed and a number of suggestions are made to improve the appearance of spiral-guided telescopic-type holders and for reducing the bulk of new holders.—B. C. W.

## REFRACTORY MATERIALS

**Thermal Conductivity. I—Concepts of Measurement and Factors Affecting Thermal Conductivity of Ceramic Materials.** W. D. Kingery and M. C. McQuarrie. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb. Part 2, 67–72). The laws of heat flow and methods of measuring thermal conductivity are considered. References are given to theoretical and practical papers on the effect of several variables. It is concluded that there are insufficient data to assess quantitatively the effect of many factors, particularly for elevated temperatures.—D. L. C. P.

**Thermal Conductivity. II—Development of a Thermal Conductivity Expression for the Special Case of Prolate Spheroids.** M. Adams and A. L. Loeb. (*J. Amer. Ceram Soc.*, 1954, **37,** Feb., Part 2, 73–74).

**Thermal Conductivity. III—Prolate Spheroidal Envelope Method. Data for $Al_2O_3$, BeO, MgO, $ThO_2$, $ZrO_2$.** M. Adams. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb., Part 2, 74–79). An absolute method of determining the conductivity of refractory materials is described. The variation of conductivity with temperature up to about 1300° C. is shown for the above oxides, and to 750° C. for an insulating firebrick.—D. L. C. P.

**Thermal Conductivity. IV—Apparatus for Determining Thermal Conductivity by a Comparative Method. Data for Pb, $Al_2O_3$, BeO, and MgO.** J. Francl and W. D. Kingery. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb., Part 2, 80–84). Apparatus for determining the thermal conductivity by a comparative method of steady-state heat flow through 1-inch cube samples is described. Values up to 600° C. are given.

**Thermal Conductivity. V—High-Temperature Method and Results for Alumina, Magnesia, and Beryllia from 1000° to 1800° C.** M. McQuarrie. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb. Part 2, 84–90). A method of measuring the thermal conductivity of refractory oxides at high temperatures is described. Heat is generated inductively in a metal 'receiver' inside a hollow specimen in the shape of a prolate spheroid, the temperature of which is measured at two points by an optical pyrometer.—D. L. C. P.

**Thermal Conductivity. VI—Determination of Conductivity of $Al_2O_3$ by Spherical Envelope and Cylinder Methods.** W. D. Kingery. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb. Part 2, 88–90). Equipment and methods for determining thermal conductivity are described using : (*a*) A spheroidal envelope specimen completely surrounding a heat source ; and (*b*) a long hollow cylinder in which a centre section is employed for a test zone. Values for $Al_2O_3$ up to 1400° C. are given.—D. L. C. P.

**Thermal Conductivity. VII—Analysis of Variation of Conductivity with Temperature for $Al_2O_3$, BeO, and MgO.** M. McQuarrie. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb. Part 2, 91–95). The results of Parts III–VI are summarized. An empirical equation is derived relating thermal conductivity of $Al_2O_3$, MgO, and BeO with temperature, up to 1800° C. Values reach a minimum at about 1500° C.—D. L. C. P.

**Thermal Conductivity. VIII—A Theory of Thermal Conductivity of Porous Materials.** A. L. Loeb. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb. Part 2, 96–99). A theory is presented relating the effective conductivity of a porous material to the conductivity of the solid material, to the emissivity of the surface of the pores, and to the size, shape, and distribution of the pores.—D. L. C. P.

**Thermal Conductivity. IX—Experimental Investigation of Effect of Porosity on Thermal Conductivity.** J. Francl and W. D. Kingery. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb., Part 2, 99–107). Samples with controlled size, shape, orientation and emissivity of pores were tested.—D. L. C. P.

**Thermal Conductivity. X—Data for Several Pure Oxide Materials Corrected to Zero Porosity.** W. D. Kingery, J. Francl, R. L. Coble, and T. Vasilos. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb., Part 2, 107–110). The thermal conductivities of several other oxide ceramics have been measured and are reported. Data for 15 pure oxides of theoretical density have been calculated. A table and graphs of the values from 100° to 1800° C. are included.—D. L. C. P.

**The Selection of Refractory Materials for Gas-Fired Equipment.** E. Blaha. (Amer. Gas Assoc. : *Indust. Heating*, 1954, **21,** Feb., 343–352). The properties of conventional and newer refractory materials are briefly described.—R. W. B.

**The High Temperature Strength of Fireclay Bricks.** W. Heiligenstaedt. (*Stahl u. Eisen*, 1954, **74,** Mar. 25, 402–405). An apparatus for determining the high-temperature strength of fireclay bricks is described. The maximum compressive stress under which a brick will not sink depends on its temperature ($\theta$) and may be expressed as $\sigma_g = 0{\cdot}9\left(\frac{1250-\theta}{100}\right)^2$ kg./sq. cm. This function was found to be valid for a number of different grades of fireclay bricks. The importance of creep or deformation rate is discussed and it is shown that the present German standard specification for fireclay bricks gives no real information about their high-temperature strength.—J. P.

**Potential Uses of Super-Refractories.** M. W. Thring. (*Research*, 1954, **7,** Feb., 54–59). The provision of refractory materials which can withstand elevated temperatures, chemical attack, and erosion is important to several major industries. Combustion-heated furnaces, recuperators and regenerators, liquid containers, electric heating elements, and instruments provide particular potential applications. High temperature research and development are dependent on the available materials (mainly oxides of silicon, aluminium, zirconium, and chromium) and various methods of achieving improved properties.—K. E. J.

**Possible Utilizations of Aluminothermal Slags.** M. Menšík. (*Hutnické Listy*, 1954, **9**, (2), 88–90). [In Czech]. Several applications of alumina slags obtained in the manufacture of ferrovanadium by the aluminothermal method are described. The slag, bonded with sodium silicate, sodium carbonate, and putty, is used as refractory coating for runners in which pig iron is oxygen-treated, for soaking-pit floors in the form of bricks, and for lining crucibles used in the manufacture of ferrovanadium. Researches on the uses of the slag for refractory bricks for other metallurgical furnaces are in progress, and initial successes are reported.—P. F.

**Refractory Types and Applications.** H. A. Robertson. (*Iron Steel Eng.*, 1954, **31**, Jan., 86–89). The author describes the principal commercial refractories. and then discusses their application in coke ovens, blast-furnaces, open-hearth furnaces, soaking pits, and reheating and annealing furnaces.

**The Historical Development of Refractory Materials Used in the Basic Open-Hearth Furnace.** H. R. Lahr. (*Refract. J.*, 1953, **29**, Dec. 505–512 ; 1954, **30**, Jan., 5–9). The refractories used in open-hearth furnaces from early times to the present are dealt with, reference being made to raw materials, manufacture, and performance. Developments in many countries are described.—D. L. C. P.

**Vermiculite in the Steel Industry: Review of Properties and Applications.** A. G. Thomson. (*Brit. Steelmaker*, 1954, **20**, Feb., 64–65). The author outlines the properties of vermiculite and indicates some of its present uses in the steel industry. These include furnace and regenerator insulation, anti-piping additions to ingot tops, and insulating ingots which are transported hot.—G. F.

**The Foam Method of Producing Insulating Refractories.** S. Pawlowski. (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6**, (6), 305–313). [In Polish]. On the basis of laboratory experiments optimum conditions for the production of insulating refractories by a foam method are recommended.

## BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

**Iron Reduction in Fluid Beds.** (*Chem. Eng.*, 1953, **60**, Sept., 398–400). U.S. Patent No. 2,638,414 concerning the reduction of iron ore to carbon-saturated pig iron is discussed. The hydrogen used for fluidizing is obtained from natural gas by regenerative pyrolysis. Ore of 50$\mu$ up to 10 mesh, preheated to 1200° C., is charged into the reduction chamber which is kept at 700–800° C. by preheated air.—A. G.

**The Making of Iron in a Blast Furnace.** G. D. Elliot. (*Trans. Inst. Chem. Eng.*, 1953, **32**, (1), 50–56). The developments of the past hundred years in the design of blast-furnaces and in the mode of operation are described and reviewed. The empirical nature of these developments, and the influence on them of constructional requirements, are demonstrated. The need for a chemical engineering approach to the problems now arising is suggested.—B. G. B.

**Pig Iron Production Problems.** S. Henkel. (*Met. u. Giesserei Techn.*, 1954, **4**, Mar., 101–105). The development of the low-shaft furnace and direct processes is traced and the smelting of lean acid ores is discussed in detail. The direct process is found to be preferable because of lower costs and coke consumption. By using the direct process (*e.g.*, Krupp-Renn) with subsequent remelting in the high or low-shaft blast-furnace, coke consumption can be reduced to 12% of that required in direct basic crude-ore smelting in the low-shaft furnace, which should therefore only be used for rich ores or remelting the product of the Krupp-Renn process.

**The Lubatti Process for the Reduction of Iron Ores.** C. Reschke. (*Stahl u. Eisen*, 1954, **74**, Feb. 25, 291). This Italian process employs a basin-shaped furnace without top. The burden consists of powdered ore, pyrites residues, or concentrates, and fine coal and coke. Power is supplied from spherical graphite electrodes which are supported on water-cooled copper tubes. In action, the electrodes are buried in a slag resting on a layer of molten iron. The burden is distributed on the slag ; metal and slag are occasionally tapped from separate tap-holes. The advantages of this furnace are that it employs fine ores and fine coal and coke only, and metallurgical coke is not required. It produces an iron with a low sulphur content and because of the finely divided state of the additions, there is a pre-reduction of the ores in the burden by the carbon monoxide from the slag. The utilization of the carbon is therefore greater than in the blast-furnace, though as yet no closed furnaces have been constructed to make use of the waste gases which still contain some carbon monoxide. Heat loss is small because of the insulating action of the burden on the slag, and electrode consumption is low. Efficiency is practically independent of furnace size. Constructional costs are low and the method can be used for the reduction of other oxide ores.—J. P.

**Desulphurizing Pig Iron.** E. Braaten. (*Tidsskr. Kjemi, Bergvesen, Met.*, 1953, **13**, Dec., 223–231). [In Norwegian]. A detailed review of research into methods of desulphurizing pig iron discusses the reactions taking place when using metallic magnesium, $Na_2CO_3$, and CaO. The last has been used in powdered form at the Domnarfvet plant since 1947 and results are given of the major tests in which 99% and 77·5% of sulphur were removed. Comparative cost analyses are given for desulphurizing using soda and lime, and for both blast- and electric furnaces.—G. G. K.

**Contribution to the Study of Cyanides, Scaffolding, and Disintegration in the Blast-furnace Stack.** Logeling. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (3), 465–492). The build-up of alkalis within the furnace and the reactions whereby these may result in cyanide formation are considered. The harmful effects of cyanides on furnace operation, namely, scaffold formation and the disintegration of stack linings, are dealt with in detail. Possible remedies to overcome or reduce these ill effects are discussed.—A. G.

**Better Distribution with High Speed Tops.** (*Steel*, 1954, **134**, Feb. 1, 96–99). The Interlake Iron Corp. blast-furnaces have been equipped with fast revolving (20 r.p.m.) small-bell hoppers. It is shown how this results in improved stock distribution in the bells and furnace. Significant improvements have resulted in output, coke rate, and flue-dust rate, and the scheme is recommended.—D. L. C. P.

**On the Change of Raw Materials and Subsequent Pig Making Operations at the Wanishi Iron Works.** T. Onoda. (*Tetsu to Hagane*, 1950, **36**, Nov., 523–530). [In Japanese]. The effects on blast-furnace operation caused by the use of domestic coal and iron ore, instead of imported materials, under wartime conditions, are explained.—K. E. J.

**Surphur in Silicate and Aluminate Slags.** F. D. Richardson and C. J. B. Fincham. (*J. Iron Steel Inst.*, 1954, **178**, Sept., 4–15). [This issue].

**Study on the Oxidation Equilibrium of Ferrous Sulphide and Manganese Sulphide by Carbon Dioxide.** T. Uno, K. Kanbara, and E. Homma. (*Tetsu to Hagane*, 1950, **36**, Oct., 479–485). [In Japanese]. Thermodynamic data are presented for the reactions $3FeS + 10\ CO_2 \rightleftharpoons Fe_3O_4 + 3SO_2 + 10\ CO$ in the range 690–890° C., and the range 600–1000° C. (18 references).

**On the Equilibrium among Silicon in Molten Iron, Molten Slag and $H_2$-$H_2O$ Mixed Gas.** K. Sanbongi and M. Otani. (*Tetsu to Hagane*, 1950, **36**, May, 175–180). [In Japanese]. Measurements were made of the equilibrium of the reaction $(SiO_2)_{sat} + 2\ H_2 \rightleftharpoons [Si] + 2\ H_2O$ in the temperature range 1500–1600° C. The temperature coefficient of the equilibrium constant was determined.—K. E. J.

**Temperature Distribution in the Hearths of Blast Furnaces.** V. Paschkis and T. Mirsepassi. (*Iron Steel Eng.*, 1954, **31**, Feb., 53–59). This paper describes a study on the temperature distribution in blast-furnace hearths by computation methods. The work was carried out jointly by Columbia University and the Association of Iron and Steel Engineers.

**Diffusion of Elements in Liquid Iron.** B. V. Stark, E. V. Chelishchev, and E. A. Kazachkov. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1951, (11), 1689–1695). Experimentally determined values of the coefficients of diffusion of manganese and silicon in molten iron are given. The experimental technique used for the determination is described.—V. G.

**Consett Iron Company Limited: The Blast Furnaces.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 49–53). Three blast-furnaces of 20 ft. hearth dia. have been erected at the Consett Iron Co., Ltd., during the reconstruction programme. Details are given of the furnace design and construction, charging equipment, cast house, hot-blast stones, clay-gun control gear, and gas-cleaning plant.—G. F.

**Practical Experiences with Twin Cowper Stoves.** G. Naumann. (*Met. u. Giesserei Techn.*, 1954, **4**, Jan., 13–15). As there is no combustion chamber in twin Cowper stoves, the flue gases can be introduced into the checker work at a higher temperature. Because the two regeneration chambers are close together and insulation is excellent, radiation losses are

reduced to a minimum. Exit gas temperature is comparatively high owing to the high gas velocity, but it could be considerably reduced by suitable checker work construction and reducing the cooling period.—L. J. L.

## TREATMENT AND USE OF SLAGS

**Production of Light Building Materials by Sintering Boiler Slag and Other Waste Materials.** W. Sabela. (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6**, (6), 329–337). [In Polish]. The production of light building materials by sintering boiler slag with other waste products, including blast-furnace slag, was investigated. Boiler slag contains enough unburned coal to supply the fuel necessary for sintering and the sinters obtained from some mixes possessed satisfactory bulk density and strength. However, the capital cost of the plant precludes this method of production.—V. G.

**On the Basicity of Slags.** Y. Matsushita, K. Mori, and E. Yamamoto. (*Tetsu to Hagane*, 1950, **36**, Dec., 587–588). [In Japanese]. The formation of complex anions containing oxygen from acidic components is discussed. Basicity, derived from considerations of binding energies, was found to bear an exponential relationship to the Martens scratch hardness in 28 slag samples.—K. E. J.

**The Action of Calcium Sulphate on the Setting of Sulphate-Rich Metallurgical Cements and of Blast-Furnace Slag Cements.** L. Blondiau and Y. Blondiau. (*Silicates Indust.*, 1953, **18**, Nov., 379–382 ; Dec., 411–416). Setting of common blast-furnace slag cements having a normal content of Portland cement clinker is retarded by calcium sulphate on account of the formation of a complex hydrated aluminate with one molecule of calcium sulphate, the former being gelatinous and unstable. Setting of sulphate-rich cements is accelerated by excess of calcium sulphate because of the formation of hard needle-shaped crystals of a stable sulphate of aluminium containing three molar equivalents of $SO_4$.—P. F.

## PRODUCTION OF STEEL

**Consett Iron Company Limited: History of the Company.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 9–16, 41). This history of the Consett Iron Co., Ltd., covers the period from 1840, when the company's forerunner, the Derwent Iron Co., was formed, to the present day. It includes an outline of post-war planning and reconstruction of the works.—G. F.

**Consett Iron Company Limited: Design and Construction of the Plant.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 17–21). An account is given of the implementation of the Consett reconstruction plans by the consulting engineers, the International Construction Co., Ltd. A general description is given of the various operating units and installations, and some of the problems encountered are detailed.

**Consett Iron Company Limited: Design of the Buildings.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 22–23, 41). The design of the buildings concerned in the Consett reconstruction programme is briefly discussed from both the architectural and structural engineering points of view.—G. F.

**Consett Iron Company Limited: Civil Engineering.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 24–33). This article deals with the foundations and structures (except steel superstructures) involved in the complete Consett reconstruction scheme. The factors taken into consideration are indicated, and details are given of the four main stages of the scheme, namely : War-time reconstruction, immediate post-war reconstruction ; new slab, bloom, and billet mill ; and construction of a railway triangle.—G. F.

**Consett Iron Company Limited: General Steelwork Construction.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 34–41). Details are given, in chronological sequence, of the erection of the buildings at Consett to house the soaking pits, stripper and mould bay, new mill, and Bessemer duplex plant. The finished buildings are also described in detail.

**Consett Iron Company Limited: Steel Melting Shop.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar., 1 54–57). Steelmaking at Consett is by the hot-metal/scrap process, with seven 150-ton basic and one 80-ton acid open-hearth furnaces and a 1000-ton inactive mixer, and also by the duplex process with a 1000-ton inactive mixer and two 25-ton acid Bessemer converters working in conjunction with the open-hearth furnaces. Brief details are given of the plant, particular attention being given to the ladle cranes.—G. F.

**Low Moor Alloy Steelworks, Limited: Low Moor Fine Steels, Limited: Yorkshire Rolling Mills, Limited.** (*Brit. Steelmaker*, 1954, **20**, Feb., 50–58). A general outline is given of the layout and equipment of the Low Moor group of companies at Bradford. The main items of plant which are considered are the melting shop, casting bay, continuous casting machine, double duo rod and bar mill, producer gas plant, heat-treatment furnaces, and the ancillary equipment for the new extrusion press.—G. F.

**Developments in the Iron and Steel Industry During 1953.** I. E. Madsen. (*Iron Steel Eng.*, 1954, **31**, Jan., 120–158). A comprehensive survey is given of all developments in the iron and steel industry in the U.S.A. and in other countries. Economic considerations are included.—M. D. J. B.

**Evolution of the Thomas (Basic Bessemer) Steelmaking Progress in Europe.** G. Husson. (*Metal Progress*, 1954, **65**, Jan., 94–96, 168–176). An account of recent advances made in European basic-Bessemer practice is given. These include optical methods of determining the end-point of the operation, the temperature of the bath, and the reduction of the nitrogen content of the metal by addition of iron ore or with oxygen-enriched blast.—B. G. B.

**Study of the Elimination of Silicon from Irons by Preblowing.** Tavard. (*Centre Doc. Sid. Circ. Inform. Tech.*, 1953, (6), 971–983). Nine trials on the preblowing of a basic converter were made. Desiliconization proved possible without appreciable manganese loss and the iron temperature was raised. Iron losses were significant but reduced by the presence of lime in the slag. In an acid converter, excessive losses of iron and manganese were observed on preblowing. Additions of basic open-hearth slag to combine with the silica produced are recommended. The influence of slag basicity on silicon and manganese removal was also studied.—A. G.

**Remarks on the Usefulness of a Second Lime-Soda Slag in the Converter.** Delong and Demartean. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (6), 961–970). Results are given for six charges blown with the normal cycle for two slags without stirring of the second slag. It was found that solid ferromanganese additions impeded dephosphorization and that a second slag of limestone and sodium carbonate was an efficient remover of phosphorus, and to a lesser extent of sulphur. The nitrogen content was not, however, improved. Trials were also made to eliminate the necessity for skimming when casting by using a coagulating second slag.—A. G.

**A Method of Working to Obtain Basic-Bessemer Steel Low in Nitrogen, Phosphorus, and Sulphur, Using Oxygen-Enriched Air.** P. Leroy, M. Gombert, and B. Trentini. (*Rev. Mét.*, 1954, **51**, Jan., 45–72). An investigation has been made to determine the optimum conditions for the regular production of basic-Bessemer steel with 0·005–0·007% $N_2$, <0·035% P, and <0·035% S, without resorting to steam or carbon dioxide in the blast, pre-refining of the iron, or the Perrin process. Trials to develop a suitable refining technique and results obtained are reported. With an oxygen-enriched blast and suitable oxidizing additions, 90% of the steel made fulfilled the above specification. This regularity of operation was achieved by employing a low static bath height, controlling the blowing rate by the volume-rate meter, the use of an immersion pyrometer, and careful weighing of all additions.

**Increasing the Life of Basic Converter Linings.** P. Metz. (*Stahl u. Eisen*, 1954, **74**, Jan. 1, 10–24). Observations on the wear of basic converter linings have shown that good life is obtained by : (1) The highest amount of residual carbon, graphite being preferable to amorphous carbon ; (2) the densest possible texture ; and (3) the largest possible proportion of coarse grains. The residual carbon can be increased by raising the proportion of intragranular tar in the tar-dolomite mixture, by rejecting hydrated dolomite, by a suitable temperature schedule during firing of tar-dolomite, and by the use of polymerization agents. Some improvements in dolomite plants have led to a preliminary increase in converter life. The density of the texture and the proportion of coarse grains are in direct relation to the grist of the dolomite. Preliminary tests have indicated the suitable grain sizes. Replacement of wooden pegs by metal tubes, the introduction of vibrators, and particularly the use of auxiliary vibration after heating the converter bottoms to 150–250° C. simplify and improve bottom preparation. Firing of seals between brickwork and bottoms by an oil burner has given them a longer life and saved time. These measures have greatly improved lining life at the Belval steelworks.—J. P.

**The Favourable Influence of Carbon on the Durability of Coked Tar-Dolomite Mixtures.** R. Gregoire and A. Decker. (*Stahl u. Eisen*, 1954, **74**, Jan. 1, 24–26). In order to determine the influence of carbon content in conventional tar-dolomite converter linings, laboratory tests have been carried out on fired tar-dolomite bodies in an electric furnace. High-iron low-phosphorus, and low-iron high-phosphorus slags were used as corrosive media. Crucibles were made by boring out the tar-dolomite blocks, slag was placed therein, and the amount of attack noted after heating. It was found that a higher carbon content protects the refractory in two ways. The higher the carbon content, the more slowly does the decarburized zone extend inwards and therefore the more slowly can aggressive slag follow. In addition, the carbon holds the dolomite together ; when the carbon content is high, it takes longer to burn away and leave an unsupported layer of dolomite.—J. P.

**The Metallurgy of Top-Blowing of Steel.** H. Rellermeyer and T. Kootz. (*Stahl u. Eisen*, 1954, **74**, Mar. 25, 381–395). High and low phosphorus pig irons have been subjected to top-blowing with air, oxygen-enriched air, and pure oxygen. Heat loss or need for cooling additions depends mainly on the length of the refining period. Free oxygen in appreciable quantity in the waste gases was detected only when blowing with air. The higher the temperature at the point of impact of the jet, *i.e.*, the higher the melt temperature, and the higher the oxygen content of the gases, the less is the amount of oxygen required for carbon removal. Carbon removal occurs non-uniformly and to a variable extent ; even under a slag high in FeO, carbon removal can be delayed for a long time. This is due to a pronounced delay in boiling, the oxygen content of the bath being greatly in excess of the equilibrium value for a CO pressure of 1 atm. When such a supersaturation is relieved it generally leads to slopping. In contrast to the sluggish carbon removal, the interchange between iron and manganese attains equilibrium. Slagging of manganese and dephosphorizing are, however, influenced by the composition of the charge and the extent of carbon removal. Dephosphorizing can be completed after carbon removal only with high iron losses if carbon removal proceeds without delay. On the other hand, dephosphorizing can be completed before removal if the carbon reaction is sluggish. The nitrogen content of the finished steel is no higher with top-blown air than with oxygen. After a nitrogen loss at the beginning of the blow, there occurs a nitrogen pick-up, depending on temperature, only during the after-blow.—J. P.

**Austrian Top-Blown Steel Process Has a World-Wide Success.** O. Cuscoleca. (*Maschinenwelt u. Elektrotechnik*, 1954, **9**, Jan., 6–7). The top-blown basic-Bessemer converter process using oxygen (the L.D. process) is briefly described, and its advantages and applications outlined.—L. D. H.

**New Methods of Steelmaking in the Basic Converter: Possible Application of the Vertical Oxygen Injection Process to British Practice.** D. J. O. Brandt. (*Iron Coal Trades Rev.*, 1954, **168**, Feb. 26, 511–514). The author critically examines the latest techniques of steelmaking in the basic converter, dealing first with the use of mixed blasts of oxygen with carbon dioxide or superheated steam, and then with the Austrian L.D. process involving vertical oxygen injection. The possibilities of applying the latter process to British steelmaking is also considered.—G. F.

**Planning and Construction of Oxygen-Blown Converters.** H. Hofmeister and C. Herrmann. (*Maschinenwelt u. Elektrotechnik*, 1954, **9**, Jan., 3–5). An historical survey is given of the development of the Austrian process of top-blowing converters with commercially pure oxygen (the L.D. process). The local conditions, which are favourable to the process, are outlined, a description of the process is given, and its advantages and possibilities are indicated.—L. D. H.

**Notes on the Development of the Modern Open-Hearth Furnace with Special Reference to the Maerz Port.** F. W. Morawa. (*Met. u. Giesserei Techn.*, 1954, **4**, Jan., 3–12). Production costs per ton of steel are analysed, the development of the Maerz type furnace is outlined, and production costs for the ordinary and the Maerz furnaces are compared.—L. J. L.

**The Application of Melting Shop Refractories in the Diósgyör Open-Hearth Steelworks.** L. Németh. (*Kohászati Lapok*, 1952, **7**, Mar., 65–71). [In Hungarian]. Reactions between molten steel and slags with refractories were studied, and the behaviour of sillimanite spouts was examined.—R. A. R.

**Slag-Metal Equilibria.** F. Muñoz del Corral. (*Inst. Hierro Acero*, 1953, **6**, Oct.-Dec., 338–350). [In Spanish]. The author explains the use of the ionic theory to obtain an improved qualitative interpretation of slag-metal reactions.

**Spray Patching of Silica Roofs of Open-Hearth Furnaces.** G. Leiber. (*Stahl u. Eisen*, 1954, **74**, Mar. 11, 328–330). A method is described by which the silica roofs of open-hearth furnaces may be patched during melting down or after charging. The patching material is not specified but it contains zirconia. It is sprayed damp from a water-cooled jet. The patching sinters and adheres well to the silica brickwork. Considerable prolongation of roof life at the August-Thyssen works has been possible, where front and back walls have also been treated.—J. P.

**British All-Basic Open-Hearth Furnace Trials.** A. Mund. (*Stahl u. Eisen*, 1954, **74**, Feb. 11, 197–207). The trials on five British and one Dutch furnaces carried out under the ægis of the All-Basic Furnace Sub-Committee of the British Ceramic Res. Assoc. and B.I.S.R.A. during the period 1948–1951, and reported in Iron Steel Inst. Special Report No. 46, 1952, are critically discussed and the results are compared with continental findings.—J. P.

**De-Oxidation Practice for Steel.** W. Koch and F. Wever. (*Stahl u. Eisen*, 1954, **74**, Feb. 25, 264–271). The influence of composition on the rate at which de-oxidation products rise in steel is discussed. When aluminium is added with the de-oxidant, the resulting inclusions are slow to rise, whereas fluid manganese-iron silicates containing little aluminium rise rapidly and leave a steel with a small number of inclusions. Unfortunately, these liquid de-oxidation products tend to form envelopes around primary crystals and induce hot shortness. The following method of de-oxidation has been tested and found to give reduced inclusion count. The steel at tap is de-oxidized with silicon-manganese alloys to give liquid oxides which rise readily. After standing for some time, the residual oxygen is reduced to desired levels with small amounts of silicon or aluminium. For use in the works, a method has been devised for introducing the final de-oxidants into the ladle. This employs the de-oxidant cast into steel tubes which are then immersed as far as the bottom of the ladle. The de-oxidant reacts from the bottom upwards as the steel tube melts away. Trials have shown the usefulness and the favourable results obtained by this method.—J. P.

**Deoxidation of Steel.** (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (5), 820–822). The use of aluminium and manganese as deoxidizers is discussed in relation to such problems as forgeability. Assessing quality by longitudinal and transverse impact strengths, the replacement of ferrosilicon for killing steel by silicon-zirconium or silicon-titanium results in a slight improvement in poor casts.—A. G.

**The Refining of Iron and Its Relation to Slags.** J. Navarro Alcacer. (*Inst. Hierro Acero*, 1953, **6**, Oct.-Dec., 321–337). [In Spanish]. The author reviews the theory of slag control and the ionic theory. He discusses desulphurization, dephosphorization, and the refining in the cupola and electric furnace, and explains the constitution of slags.—R. S.

**The Technological Basis of Making and Pouring Carbon Steel in 50-Ton Open-Hearth Furnaces.** J. Páleníček. (*Hutník*, (Prague), 1954, **4**, (2), 39–43). [In Czech]. A description of all stages of making carbon steels as practised in Czechoslovakia is given. Formulæ for speed control in rapid pouring and for the time the ingots remain in the moulds before stripping are discussed. The furnaces considered operate with cold charges ; walls are of magnesite and the suspended roofs of chrome-magnesite brick. Producer gas is used, sometimes in conjunction with coke-oven gas.

**Alloy Steel Production in 50-Ton Open-Hearth Furnaces.** L. Milata. (*Hutník*, (Prague), 1954, **4**, (2), 47–50). [In Czech]. The principles and methods involved in all stages of open-hearth alloy steel production are critically surveyed. Changes in the proportions of lime and ore additions, the replacement of pure ferromanganese by cheap blast-furnace ferromanganese, and the resulting decrease in the basicity and viscosity of the slag lead to considerable savings of time in the periods of melting and phosphorus reduction.—P. F.

**Demolition of a 20-ton Open-Hearth Furnace and Erection of a new 40-ton Open Hearth Furnace in 22 Days.** W. Brenner. (*Met. u. Giesserei Techn.*, 1954, **4**, Jan., 15–18). A detailed description of the demolition of a 20-ton open-hearth furnace and the erection of a new 40-ton furnace at the Gröditz steelworks in Eastern Germany is given.—L. J. L.

**The Use of Limestone in Open-Hearth Furnace Charges.** A. Děkanovský. (*Hutník*, (Prague), 1954, **4**, (1), 9–11). [In Czech]. An analysis of the relative advantages of charging lime and limestone is made. It is concluded that, apart from the well known economic advantages of using limestone, it also accelerates the heat and improves the quality of the steel. The best methods of charging it are discussed.—P. F.

**Standard Dimension of Oil-Fired Open-Hearth Furnace.** T. Kinoshita. (*Tetsu to Hagane*, 1950, **36**, Nov., 570–575). [In Japanese]. Recommendations are put forward for standardizing dimensions of new installations and renovated furnaces in Japan.—K. E. J.

**Modification of Open-Hearth Furnaces to Operate on Fuel Oil.** (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (5), 805–810). Accounts are given of four works which have recently switched over to fuel oil firing. In general, there is both an increase in production and a saving in calories but less steam is raised by the regenerators.—A. G.

**Troubles Arising from the Use of High-Sulphur Fuel Oil.** (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (5), 810–814). Desulphurization of fuel oils is not technically feasable but preliminary gasification is more promising. The factors governing sulphur pick-up in open-hearth steelmaking have been studied at Denain works. With heavy scrap, more lime, high manganese, and careful refining, sulphur contents between 0·025 and 0·028% have been achieved in oil-fired furnaces.—A. G.

**Tar-Fired Furnaces.** Husson. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (5), 814–815). Information from a visit to English, Scottish, and Welsh works is reported. The use of tar presents no difficulties if certain precautions are taken, *e.g.*, never mixing tar and fuel oil. English fuel oils contain only 2·5% sulphur and their irons are richer in manganese so that sulphur pick-up is less.—A. G.

**Use of a Large Proportion of Hot Iron in the Charge.** Devernay. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (5), 815–820). A description is given of the equipment and methods of operating open-hearth furnaces at the Appleby-Frodingham steelworks. The steel produced is suitable for the products made but it would be difficult to obtain steels low in sulphur and phosphorus. The consumption of calories in mixer and open-hearth furnaces is high, but refractory consumption is very low.—A. G.

**On the Combustion in Open-Hearth Furnace in which Producers Gas Is Used (I).** Y. Doi. (*Tetsu to Hagane*, 1950, **36**, Nov., 531–536). [In Japanese]. The use of oxygen for combustion of producer gas shortens melting time. Compressed air may also be used. In tests on a Venturi-type acid open-hearth furnace, melting times were reduced by 14% (using oxygen) and 13% (using compressed air) with fuel savings of approx. 10%.—K. E. J.

**Oxygen Shortens Open-Hearth Meltdowns.** O. D. Eyre. (*Steel*, 1954, **134**, Feb. 8, 116–119). Experience with auxiliary oxygen/coke-oven gas burners on 170-ton open-hearth furnaces at Ashland is described. Output was increased and fuel consumption improved without detriment to other operating conditions. The auxiliary burners were incorporated in the corner coolers. Oxygen used was 532 cu. ft./ton. Figures are given comparing the heats with previous compaigns without oxygen.—D. L. C. P.

**Kaiser Steel Corporation's Fontana Plant.** T. J. Ess. (*Iron Steel Eng.*, 1954, **31**, Feb., K2–K20). A detailed description is given of the Fontana plant of the Kaiser Steel Corp.—M. D. J. B.

**The Water Supply at Stahlwerke Bochum A.G.** H. Priester. (*Stahl u. Eisen*, 1954, **74**, Jan. 1, 34–35). The measures taken to conserve and recirculate water are described. Great savings of water were achieved by hot cooling of open-hearth furnace door frames, which also produced 1500 tons of steam per month from the three doors of a 65-ton furnace.—J. P.

**Report of Steel Making Division, Investigation Committee of the Iron and Steel Institute of Japan. (I).** H. Kikkawa. (*Tetsu to Hagane*, 1950, **36**, Oct., 510–513). [In Japanese]. A progress report is given on work including gas-producer operation, use of fuel oil, open-hearth design and construction, high-quality steelmaking in the open-hearth furnace, production of normal quality steel in the electric furnace, and the use of oxygen in the open-hearth furnace.—K. E. J.

**Synthetic Studies on Steel Making Reactions (II).** Y. Matsushita and K. Mori. (*Tetsu to Hagane*, 1950, **36**, July, 292–293). [In Japanese]. The melting and vaporization of iron were considered on the basis of the theory of process rates. Applications of statistics to problems of steelmaking operational data were indicated.—K. E. J.

**Modern Scrap Yard Keeps Pace with Market.** J. B. Schlossberg. (*Iron Age*, 1954, **173**, Jan. 14, 118–121). The track layout and work areas of a modern scrapyard are described. Equipment employed includes 40-ton Diesel-electric locomotive cranes, 55-in. magnets, a baling press, crushing machine, alligator shears, and burning torches. Stress is laid on the correct location of the weighbridge to facilitate the flow of traffic.—A. M. F.

**Growth Possibilities of Electric Furnace Carbon Steel.** W. C. Wheeler. (*Iron Steel Eng.*, 1954, **31**, Feb., 85–92). The author discusses the possibilities of the growth of carbon steel production in the electric furnace based upon data for the production of steel ingots by all processes as published by the American Iron and Steel Institute.—M. D. J. B.

**Costs Favor Electric in Cold Metal Shops.** L. F. Reinartz and L. F. Barnes. (*Steel*, 1954, **134**, Jan. 25, 96, 98, 99). **Electric Furnace vs. Open Hearth in Cold Metal Shops.** L. F. Reinartz and H. C. Barnes. (*Amer. Iron Steel Inst. Regional Tech. Meetings*, 1953, 331–349: *Iron Steel Eng.*, 1954, **31**, Jan., 114–119: *Blast Furn. Steel Plant*, 1954, **42**, Mar., 345–350, 359.) After discussing the fundamental aspects of steelmaking in basic open-hearth and electric furnaces, the authors compare fuel and electricity costs, materials handling methods, the qualities of steels produced, and operating, material, and installation costs. If cheap scrap were available the cost might be 7 dollars less per ingot ton produced in the electric furnace.—M. D. J. B.

**Graphite Electrodes.** R. N. Hader, B. W. Gamson, and B. L. Bailey. (*Indust. Eng. Chem.*, 1954, **46**, Jan., 2–11). Details are given of modern processes used to manufacture synthetic graphite and amorphous carbon products from petroleum coke and coal-tar pitch. The uses of these products are surveyed, particularly for large electrodes for furnaces. The output of steel from electric furnaces is increasing at twice the rate for all steel, and electric furnaces are economic competitors with open-hearth furnaces. Other metallurgical developments are reviewed. (14 references).—K. E. J.

**Effect of Chromium on the Non-Metallic Inclusion in Molten Steel (I).** H. Ishizuka. (*Tetsu to Hagane*, 1950, **36**, Nov., 537–542). [In Japanese]. In basic arc furnace practice, ferrochromium addition markedly decreased the amount of non-metallic inclusions; it is preferably made after that of ferromanganese. The initial amount of inclusions, and the reduction effected, are dependent on slag basicity, and the optimum $CaO/SiO_2$ ratio desirable before ferrochromium addition is 3·2–3·5.—K. E. J.

**Large High-Frequency Furnaces.** (*Found. Trade J.*, 1954, **96**, Jan. 21, 73–74). This plant has already been described by T. Hahn, *see* " Coreless Induction Furnace Plant of 12 tons Capacity at the Kilsta Steelworks (Sweden) " *J. Iron Steel Inst.*, 1954, 176, Apr., 455.

**Energy Consumption of Induction Furnaces.** K. H. Brokmeier. (*Elektrowärme-Techn.*, 1954, **5**, Feb., 25–27). It is shown by a few examples that the energy rating of induction heated melting furnaces is not, by itself, a satisfactory criterion in designing or buying these furnaces. The method of using a furnace also influences its performance, as continuous use with steady or fluctuating temperatures and intermittent use have important effects.—P. F.

**Factors Affecting Production Rate on an Electric Furnace Melting Rimming Steel.** W. W. Black, and C. R. Taylor. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10**, 14–24). The authors studied factors affecting the production rate of rimming steel in a 70-ton electric furnace, using multiple curvilinear correlation methods to analyse data from 100 triple charge heats. Particular attention is given to the effect of oxygen during melting ; its use is found to be beneficial only on the second and third charges. The results are presented graphically.—G. F.

**Smoke, Dust, Fumes Closely Controlled in Electric Furnaces.** R. S. Coulter. (*Iron Age*, 1954, **173**, Jan. 14, 107–110). Experience with smoke control from three electric arc furnaces is described. Cotterel-type electrical precipitation is used and this collects up to 20,000 lb. of dust daily. Controlled negative furnace pressure has eliminated fume emission from the electrode openings. For maximum efficiency of the precipitators the gases are cooled to 139° F. with a relative humidity of 32½% in spray towers.—A. M. F.

**Elimination of Dust and Fumes from Electric Furnaces.** J. G. Liskow. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 32–40). The author discusses the problem of dust and fume removal from electric furnaces and contends that dust control is now possible and practical. By fitting a properly designed hood and using a reasonable exhaust volume, the escape of over 0·3 to 0·4 grains/cu. ft. can be prevented.—G. F.

**A Unique Approach to the Collection of Fumes from Electric Furnaces.** M. I. Dorfan. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 41–60). The author suggests a method of fume control in electric furnaces which involves an exhaust system at points in the furnace roof and maintaining a slight negative pressure within the furnace. The exhaust gas is passed for cleaning through constantly moving beds of granular material in an " Impingo " filter, the design of which is outlined.—G. F.

**Relation of Power Input and Controls to Efficiency and Quality of Steel Production.** C. W. Vokac. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 62–85). The author explains the meanings of the terms ' power factor,' ' load factor,' and ' surge factor,' and discusses their significance in the economics and efficiency of electric furnace steel production. Correct design of the equipment to maintain high values of these factors is described, particular attention being given to the furnace regulator and electrode control. Other design features mentioned include an automatic electrode clamp, lining and earthing of the shell, and tilting and charging equipment.—G. F.

**Standardization of Electric Furnace Roofs.** L. L. Gill. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 206–215). The author discusses the desirability for standardizing the design of electric furnace roofs and considers the advantages to be gained by both the steelmaker and the brick producer. Some of the commonly used roof designs are illustrated, and an outline is given of the advantages of using standard and semi-standard roof bricks instead of special shapes.—G. F.

**Standardization of Electric Furnace Roofs.** C. Cline. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 216–217). The design of electric furnace roofs at the Canton (Ohio) works of Timken Roller Bearing Co. has been standardized to a large extent. A brief indication is given of the resulting increase in roof life and reduction in costs.—G. F.

**Substitute Sources of Chromium for Low-Carbon Chromium Stainless Steels.** N. B. McFarlane. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 231–237). The high cost of low-carbon ferrochromium has led in recent years to the development of melting practices for stainless steels whereby chromium can be obtained from stainless scrap, high-carbon ferrochromium, and low carbon silicoferrochromium. The author outlines some of these practices and discusses the problems involved.—G. F.

**Induction Power Losses in Electric-Arc Furnace Structures.** L. R. Stone. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 238–247). The author indicates how induction power losses occur in electric furnace structures, and describes tests of induction effects in the cases of a proposed design for an electrode clamp and of the furnace roof glands. The results indicate the undesirability of magnetic materials in a structure which constitutes a continuous magnetic path around a conductor.—G. F.

**Human Relations in the Furnace Shop.** R. Smith. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 5–14). The author discusses the factor of labour-management relations in the American steel industry, referring particularly to the Colorado Fuel & Iron Corp. He stresses the necessity for recognizing the importance of the individual worker.—G. F.

**Ingot Feeder Head Refractories.** W. T. Hale. (*Silicates Indust.*, 1954, **19,** Feb., 71–73). [In English]. Various designs and materials used for feeder heads when casting steel ingots are described. By a suitable choice of porous refractory brick an appreciable reduction in losses due to pipe formation can be achieved, but best results were obtained with recessed tiles.—P. F.

**The Use of Wooden Frames in the Pouring of Steel.** K. Říha. (*Hutník*, (Prague), 1953, **3,** (11), 246–248). [In Czech]. A crust of slag floating on the rising metal surface in the bottom-pouring of steel is objectionable as it is likely to stick to the mould wall and may cause inclusions. Control of this crust through variations in the pouring rate is inefficient. Frames of soft wood, dried at 70° C. for 48 hr., fitting just inside the mould, are inserted into the empty mould, close to the bottom. The rising steel ignites the frames which burn slowly, as the moulds are covered and little air enters. Combustion products aid the mould dressing, the frame prevents any slag crust from floating to the edges of the mould, and the dilution of the air by combustion products reduces the rate of surface oxidation of the steel. If the frames are correctly dried and dimensioned the risk of gas bubbles at the mould walls is slight. Good results are claimed. With some low-grade steels the rejects of products forged from them has been reduced by 30%.—P. F.

**Progress Report on Oxy-Natural-Gas Hot-Top Heating.** A. J. Texter, W. A. McKeen, and E. F. Kurzinski. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 172–183). The works of Firth-Sterling Inc. at McKeesport, Pa., uses oxygen/natural-gas flames for ingot hot-top heating, reducing the volume of the top to 6–7%. The development of this practice and the apparatus used are described, and an outline is given of the process, and its economic and metallurgical aspects.—G. F.

**Hot Topping.** W. R. Lysobey and R. L. Deily. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 184–188). A description is given of a burner arrangement designed for heating ingot tops by an oxy-fuel gas flame and the performance of the device in practice is indicated.—G. F.

**The Autopour.** T. J. Hoby. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 189–196). The Autopour is a mechanical method of pouring steel in which hydraulic power is transmitted to the stopper-rod slide and controlled remotely by push-buttons. The development of the method is described and practical experience of its use is discussed. It is safer and easier than conventional teeming practice and is more easily controlled.—G. F.

**Ingot-Heat Conservation: Consideration of Factors Determining Limits of Solidification Allowable Prior to Further Processing.** H. O. Howson. (*Iron Coal Trades Rev.*, 1954, **168,** Feb. 26, 491–499). The author discusses some of the factors which may limit the application of methods of ingot-heat conservation, dealing first with metallurgical considerations associated with early stripping. Attention is given to the extent of solidification permissible, according to the type of ingot cast, before charging the ingot to the soaking pits. Problems associated with equalization of temperature throughout the ingot are also considered.—G. F.

## PRODUCTION OF FERRO-ALLOYS

**Production of Manganese Slags for Manufacturing High Grade Ferromanganese by Blowing (Oxidation) Spiegeleisen.** T. Kootz, J. Willems, W. Oelsen, and H. Wentrup. (*U.S. Bur. Mines. Inform Circ.*, 7634, 1950, June). This is an English translation of a paper which appeared in *Stahl u. Eisen*, 1952, **70,** Apr. 27, 360–369. (*See J. Iron Steel Inst.*, 1951, **167,** Feb., 215).

**Norway's First Enclosed Rotary Furnace for Ferro-Alloys.** O. Braaten. (*Tekn. Ukeblad*, 1954, **101,** Jan. 21, 60–61). [In Norwegian]. The advantages of rotary furnaces in improving charge porosity and ensuring uniform distribution of the evolved gases are touched upon. Details are given of the new 6000-kW. furnace operated by the Porsgrunn A/S., containing three Söderberg electrodes. The container, lined with fireclay magnesite, and calcined anthracite weighs 300–400 tons and is rotated by a 1-h.p. motor through reduction gearing. Time taken for one revolution varies from 4 to 96 hr. The stationary top casing comprises numerous water-cooled steel sections, the charge being supplied automatically from the material hoppers above. The gases, containing up to 80% CO, are treated in an 85-h.p. scrubber unit, giving a residual dust concentration of 0·1 g./cu. m.—G. G. K.

**Silicon Losses in the Production of Ferrosilicon.** P. V. Gel'd, O. A. Esin, N. N. Buinov, and R. M. Lerinman. (*Doklady Akademii Nauk S.S.S.R.*, 1949, **67,** (6), 1073–1076). The nature of silicon losses during the production of silicon alloys was investigated. It is concluded that silicon is lost as a fine mist of silicon monoxide rather than by mechanical entrainment of burden materials in the gas stream.—V. G.

**New Metals and Alloys Plant.** (*Chem. Eng.*, 1953, **60,** Sept., 134, 136, 137). The Electrometallurgical Company's new plant at Marietta, Ohio, will shortly produce silicon, man-

ganese, and chromium ferroalloys together with ferrochromium of very low carbon content, and brief details of the plant are given. Electrolytic tungsten and manganese will be produced later.—A. G.

## FOUNDRY PRACTICE

**Mechanical Charging of Iron Foundry Cupolas.** (*Engineering*, 1954, **177,** Feb. 12, 217). **Mechanization Extended at Leyland.** (*Foundry Trade J.*, 1954, **96,** Feb. 25, 215–217). The mechanization of cupola charging at the foundry of Leyland Motors Ltd. is described. A scale car conveys drop-bottom skips from loading positions alongside the heaps of classified pig iron, scrap, and limestone in the stockyard to a position underneath the 12-ton coke hopper. The skip, after being weighed, moves on a conveyor to the hoist or telpher, which is 34 ft. high, up which it is lifted at 50 ft./min. along a mono-rail which has branches to each of the four cupolas. There is also a plant for making 2¼-lb. briquettes from cast iron turnings and borings at the rate of 540/hr. This plant deals with 20 tons of borings per 44-hr. week.—R. A. R.

**The Theory of the Experiments Having as Their Object the Reduction of Endothermic Reactions in Combustion Processes in Cupolas, and Their Results.** M. Király. (*Öntöde*, 1952, **3,** (4), 73–87 : *Kohaszati Lapok*, 1952, **7,** Apr.). The manner in which time, space, temperature, and pressure affect combustion in the cupola is examined and two melting processes, one with air scavenging and the other with air injection are described. The latter is the more economical. A heat balance for an efficiently operating cupola is presented. Basic cupola linings are also considered.—R. A. R.

**Rammed Linings for Cupolas.** J. Kulínek. (*Slévárenství*, 1954, **2,** (2), 48–50). [In Czech]. Experiences gained over 28 months with a recently developed Czechoslovak cupola lining material in two cupolas show that this comparatively cheap material is very suitable for rammed linings. A principal constituent is local kaolin ; the principal chemical components are $SiO_2$ (74%), $Al_2O_3$ (23%), $TiO_2$ (1·3%), with smaller amounts of $Fe_2O_3$, CaO, MgO. The softening point is 1670° C.—P. F.

**Operating Experience with Hot-Blast Cupolas.** B. Thyberg. (*Tekn. Tidskr.*, 1954, **84,** Feb. 2, 77–79). [In Swedish]. Details are given of the operation of two hot-blast cupolas at the Husqvarna foundry over the last two years. Inlet temperature of the gases to the recuperator is 900–950° C. max. to avoid sintering of dust particles on its elements. Outlet temperature to the cupola is 450° C. Coke charge was reduced from 14–15% to 9·5–10%, the saving due to hot blast being 3·5–4%, calculated on the weight of the iron, or 25–28% based on the original quantity of coke. With cold blast the specific melting rate was 7–7½ tons/sq. m./hr. ; with hot blast it was 10 tons/sq. m./hr. Maximum temperature rose from 1700° to 1800° C. Conversion costs were Kr. 350,000 each, which it is expected to recover in about three years.—G. G. K.

**Reactions of Some Magnesium Alloys with Cast Iron Melts.** U. Zwicker. (*Z. Metallkunde*, 1954, **45,** Jan., 31–35). In discussing the use of magnesium alloy additions in the manufacture of nodular cast iron, the author compares the mechanism of the reactions of iron–nickel–carbon–magnesium alloys with those of iron–silicon–carbon–magnesium. In the former alloy $MgN_2$ and magnesium–nickel-carbide are the most stable compounds over a wide range of compositions, and they facilitate the solution of magnesium. In the latter case the compound FeSi is the most stable, and is formed from $Mg_2Si$ with the liberation of heat and the formation of free magnesium.—L. D. H.

**Investigation on the Preparation of Magnesium Alloys for Inoculants to Produce Nodular Iron.** J. Piaskowski. (*Przeglad Odlewnictwa*, 1954, **4,** (2), 48–49). [In Polish]. The literature on the production of magnesium alloys for inoculants is briefly surveyed. The production of ferrosilicon-magnesium alloys in a crucible is described. The best results were obtained when no protective carbon or slag layers were used.—V. F.

**The Influence of the Heating Rate on the Formation of Graphitization Nuclei During the Heat-Treatment of Inoculated Malleable Cast Iron.** I. I. Khoroshev. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (2), 221–223). [In Russian]. The influence of the velocity of heating to maximum temperature and the amount of inoculant added on the formation of graphitization nuclei in white castings was investigated. Samples of iron without additions and inoculated with aluminium (0·01–0·02%) were investigated. Some of the specimens were heated from 20° to 950° C. in such a manner that the 250–420° range was covered between 0·5 and 6 hr. The other specimens were similarly treated in the 420–950° C. range. All samples were heat-treated to obtain a ferritic structure. It was found that : (1) Increasing the aluminium addition from 0·01 to 0·02% increased the number of graphitization nuclei. (2) When heating continuously 5–6 hr. should be taken to pass from 250° to 420° C. since in this range graphitization nuclei are formed which, by subsequent annealing, increase the number of graphite clusters and shorten the graphitization process.—V. G.

**The Influence of the Preliminary Isothermal Heat-Treatment on the Formation of Graphitization Nuclei During the Annealing of Malleable Cast Iron.** I. I. Khoroshev. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (1), 45–48). [In Russian]. The relationship between the process of the formation of graphitization nuclei and the duration and temperature of isothermal treatment of castings, composition of iron, modifying additions, and the rate of heating after the isothermal treatment was investigated. From data obtained it is concluded that the inoculation of malleable iron with aluminium increases the metastability of cementite, thus contributing to the formation of submicroscopic graphitization nuclei in the 280–400° C. range. This, on subsequent heat-treatment, leads to the formation of more graphite clusters (from 200 to 500/sq. mm.) enabling the first graphitization stage to be completed at 950–980° C. in 30–60 min., and the second stage in 30–90 min. These results were confirmed by many additional experiments.—V. G.

**Studies on the Mechanism of Graphite Formation at the Freezing Range of Cast Iron and that of Nodular Graphite Cast Iron. (I).** H. Tanimua, K. Matsuda, and O. Izu. (*Tetsu to Hagane*, 1950, **36,** Dec., 589–597). [In Japanese]. Both flaky and nodular graphite are formed when iron is cooled to the eutectic temperature ; in nodular cast iron, the velocity of formation is low. With magnesium-treated iron, nodular graphite can only be produced at a slow cooling rate, probably as a result of the stability of the cementite.—K. E. J.

**Outline of the Spheroidal Graphite Cast Iron.** M. Okamoto. (*Tetsu to Hagane*, 1950, **36,** Aug., 365–373). [In Japanese]. A survey is given, including some new results, of spheroidization of graphite in cast iron. The optimum contents of carbon, silicon, manganese, phosphorus, and sulphur are discussed. The mechanism of the magnesium treatment is described. Mechanical properties of the cast irons are given, and methods of producing desired properties are discussed. (25 references).—K. E. J.

**Heat-Treatment of Spheroidal-Graphite Cast Irons.** M. Ballay, R. Chavy, and J. Grilliat. (*Found. Trade J.*, 1954, **96,** Jan. 28, 91–97 ; Feb. 4, 125–128). Results are presented of a large number of tests carried out on heat-treated spheroidal-graphite cast iron. Among the heat-treatments considered are : (*a*) Graphitization of the combined carbon in white iron ; (*b*) full and partial graphitization of pearlitic iron ; (*c*) high temperature homogenization ; (*d*) normalizing ; (*e*) martensitic hardening and tempering ; (*f*) surface and local hardening ; and (*g*) relief of internal stresses. Spheroidal-graphite cast irons can be given most of the heat-treatments used for steels and in many cases existing knowledge obtained from heat-treatments on steel and grey iron can be directly applied to spheroidal-graphite irons.—B. C. W.

**High-Tensile Cast Iron.** L. Frank. (*Öntöde*, 1952, **3,** (3), 51–67 : *Kohászati Lapok*, 1952, **7,** Mar.). [In Hungarian]. The production of nodular graphite cast iron with addition of Cu–Mg and Mg–Si alloys containing 10% and 20% Mg is discussed, and the relation between composition and microstructure is examined.—R. A. R.

**The Effect of Heat-Treatment on the Mechanical Properties of Cast Iron Treated with Magnesium.** N. Hajtó. (*Öntöde*, 1952, **3,** (1), 1–18 : *Kohászati Lapok*, 1952, **7,** Jan.). [In Hungarian]. The nodular graphite cast iron first produced in Hungary was too brittle owing to too much silicon in the added alloy. Methods and trials to produce a tougher iron are described.—R. A. R.

**The Influence of Gaseous Atmospheres Containing Hydrogen on the Annealing of Malleable Cast Iron.** S. W. Palmer. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1953, **5,** Aug., 26–37). A report is presented on the influence of annealing atmospheres containing hydrogen on : (1) Rate of heating ; (2) first-stage graphitization ; and (3) second-stage graphitization of black-

heart malleable iron. The effect of such atmospheres on the first-stage graphitization of whiteheart malleable iron has also been studied.—B. G. B.

**Blackheart Cupola Malleable.** T. F. R. Hart. (*Australian Found. Trade J.*, 1953, **5,** Oct., 9, 11–16, 21–23, 25). The basis of blackheart malleable iron production, *i.e.*, graphitization by annealing iron in which the entire carbon is in the combined state as cast, is outlined. The effects of various elements on the annealing and physical properties are discussed, and the packing and annealing cycle for a typical composition (C 2·80% max., Si 0·90% max., C + Si 4·10% max., Mn 1·7 times sulphur plus 0·10 to 0·25%, P 0·10 to 0·25%, Cr 0·05% max.) is described. Details are also given of defects due to annealing and casting, and cupola melting is described in some detail, data being presented for a typical heat.—P. M. C.

**The Use of Inserts Between the Cope and the Drag in Making Steel Castings.** V. Batěk. (*Slévárenství*, 1954, **2,** (1), 14–17). [In Czech]. An annular sand slab inserted between the cope and the drag prevents them from being welded together. The application of the method in the production of gear-wheels and slide-valve discs is discussed.—P. F.

**Contribution to the Study of the Adherence of Moulding Materials to Castings.** L. Petržela. (Reports of Czech Foundry Research : *Slévárenství*, 1954, **2,** (2), Supplement). [In Czech]. Castings in the shape of split cylinders were cast round specimens of moulding materials. It was found that baking-on of sand to grey cast iron was minimized by adding anthracite dust. Graphite and coke dust proved ineffective. Coal dust additions are not suitable for steel castings.—P. F.

**Metal Penetration, Fused Sand, and Scabs on Steel Castings.** W. Kilian. (*Met. u. Giesserei Techn.*, 1954, **4,** Jan., 34–36). Theories of metal penetration are reviewed with special reference to the work of P. R. Beeley and H. T. Protheroe. (*J. Iron Steel Inst.*, 1951, **167,** Feb., 141–157). The causes of fused sand and scabs are investigated, the former being attributed to the erosive effect of the molten metal upon the mould, the latter to the effect of gas pressure on the cohesion of the moulding sand, the pressure of liquid metal upon the surface of the mould, and the air pressure within the mould. Recommendations for preventing scabs are made.—L. J. L.

**Low-Frequency Induction Furnaces in Foundries.** H. Kalpers. (*Maschinenwelt u. Elektrotechnik*, 1954, **9,** Jan., 10–12). The application of low frequency induction furnaces to foundry practice, alone or in a duplex process, is described, and their advantages are indicated. These include improved properties of the castings and a reduction in melting losses and scrap.—L. D. H.

**The Influence of Acid and Basic Electric Furnace Melting on Fluidity and Hot Tears.** P. J. Neff. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 86–99). The Indiana Harbor Works of American Steel Foundries operates one acid-lined and one basic-lined electric furnace which are otherwise identical in design, electrical equipment, output, type of scrap melted, and type of casting produced. The author outlines the methods of operation and describes comparisons made on laboratory and production castings to study fluidity and hot-tearing as related to the two practices. The results show no significant difference in fluidity, but the basic steel, by virtue of its lower sulphur content, is less prone to hot-tearing.—G. F.

**Comparison of Acid and Basic Electric Steel for Castings.** J. W. Juppenlatz and T. S. Quinn. jun. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 100–116). The authors describe several months experience in the production of similar castings by both acid and basic electric furnace practice, and present comparative data. The choice of the method of operation for producing small castings is discussed and is shown to be resolved into a matter of economics and objectives.—G. F.

**On the Melting of the Steel Castings by the Basic Electric Furnace.** T. Kinoshita. (*Tetsu to Hagane*, 1950, **36,** July, 294–306). [In Japanese]. For the production of steel for castings in the electric furnace, hydrogen should be eliminated during oxidizing, a moderate decarburizing speed should be used, deoxidation should be rapid, non-metallic inclusions must be tolerated, sulphur should be low and manganese in excess to avoid hot tearing, and the steel should be tapped above 1520° C.—K. E. J.

**A Review of Metallurgical Practices and Their Effects.** C. E. Sims. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10,** 152–171). The author summarizes and evaluates present-day knowledge on the preparation of steel for casting, and discusses the effect of certain factors on steel quality. The factors considered are the boil, dissolved gases, slag composition and slag control, deoxidation and its effect on mechanical properties and on the form of the sulphide inclusions. The effects of rare-earth additions are also mentioned.—G. F.

**Study on the Grain Size of Foundry Sand.** H. Nishihara. (*Tetsu to Hagane*, 1950, **36,** July, 306–311). [In Japanese]. When clay is mixed with sand, it should not be in such amounts as to become a washed clay. Small sand grains should be removed, and long mixing times appear to be satisfactory.

**Core Blowing Equipment and Use.** P. Dwyer. (*Foundry*, 1953, **81,** Dec., 203, 205 ; 1954, **82,** Jan., 168, 171 ; Feb., 220, 222 ; Mar., 237–238). A series of expert replies are given in response to a number of questions on American core-blowing methods. Among the problems considered are venting, diameter and number of blow holes, and suitable core sand mixtures.—B. C. W.

**The Flow of Moulding Sand.** J. Gittus. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1953, **4,** June, 560–567). Several empirical laboratory tests for measuring the flowability of moulding sands, which determines the manner in which sand flows when a mould or core is being made, have been analysed. Certain of the tests are shown to give similar results for similar groups of sands. From this it is confirmed that the same property is measured by all the tests. This property is termed the 'Bond Energy Ratio ($R$)' of the sand. Methods of determining $R$ are discussed.—B. G. B.

**Master Patternmaking Aids Production.** H. Wilson. (Inst. Brit. Foundrymen : *Found. Trade J.*, 1954, **96,** Jan. 7, 5–11 ; Jan. 14, 47–52). A number of patterns from each of the following classes are described and discussed in detail : (1) loose yellow-pine, (2) loose mahogany, (3) "plated" mahogany, (4) loose, filed and scraped metal, (5) "plated" filed and scraped metal, and (6) "plated" and fully machined metal.—B. C. W.

**Production of a Pattern of a Kaplan Turbine Rotor Blade.** M. Málek. (*Slévárenství*, 1954, **2,** (1), 9–11). [In Czech]. Experience and methods relating to the manufacture of moulding equipment, patterns, and the machining of the surface of a turbine rotor blade. The design of the blade is discussed.—P. F.

**Gating to Control Pouring Rate and Its Effect on the Casting.** F. J. McDonald. (*Amer. Foundryman*, 1953, **24,** Dec., 36–41). Results are presented of an investigation into the effect of sprue cups, sprue posts, ladle height, cross-sectional runner area, and skim cores on pouring rate and casting defects. Skim cores do not directly remove slag, but, by reducing metal velocity, they allow more slag to adhere to the top of the runner. Better control over pouring rate can be achieved by varying sprue-post diameter or by using runner chokes. To avoid casting thickness variations, the ladle height should be controlled. Providing that the metal flow is fast enough to avoid misruns, the slower the pouring rate the fewer will be the casting defects.—B. C. W.

**Pushbutton Foundry Is Approached in Automatic Molding System.** R. H. Herrmann. (*Foundry*, 1953, **81,** Dec., 154–156). A description is given of the fully automatic moulding system in operation in the malleable iron foundry of the Crane Co., Chicago. The copes and drags are produced in jolt-squeeze machines and cores inserted in the drags by a pneumatic device. After closing, the moulds are transferred to another conveyor for pouring and then pass through a cooling tunnel to the knock-out station from which the cope and drag flasks are returned automatically to the moulding lines. The system produces 1800 complete moulds every 8 hr. and requires only four men on the moulding side.—B. C. W.

**Follow Boards and Matchplates.** P. Dwyer. (*Foundry*, 1953, **81,** Aug., 195–199 ; Sept., 255–262 ; Oct., 197–199 ; Nov., 287–289). Materials and methods for making follow boards and matchplates are described in detail. Particular attention is paid to boards made from fireclay and hard sand.

**Metal Corebox Construction.** F. H. Wakeham. (*Found. Trade J.*, 1953, **95,** Dec. 24, 789). The advantages, construction, and machining of an aluminium corebox for repetition work are briefly described.—B. C. W.

**The Manufacture of Cores with Waterglass and Carbon Dioxide in Iron Foundry Practice.** F. Naumann. (*Met. u.*

*Giesserei Techn.*, 1954, **4**, Mar., 116–117). For iron castings, coal dust is added to the mixture of dry quartz sand and waterglass. The best mixture was found to be 72·4% sand, 10·4% used sand, 10·4% coal dust, and 6·8% waterglass. When the core box has been filled with the mixture, carbon dioxide is blown in.—L. J. L.

**A New Core Making Process.** F. Brunn. (*Met. u. Giesserei Techn.*, 1954, **4**, Mar., 113–116). The process described differs from orthodox methods in that a mixture of quartz sand (free from clay) and waterglass is used, which is solidified by blowing in carbon dioxide. No drying or baking is necessary and the process is very rapid.—L. J. L.

**Rollmaking Art Goes Modern.** (*Steel*, 1954, **134**, Jan. 18, 82–87). Recent foundry practice is described, including the systems of double pouring.—D. L. C. P.

**Casting Long Rolls.** B. Hjelmqvist. (*Gjuteriet*, 1954, **44**, Jan., 11–12). [In Swedish]. Details are given of procedure for moulding and casting four types of cast-iron rolls, 6 m. long, wall thickness 50 mm., and outside dia. 350–800 mm., weighing 3 to 6 tons. Rolls are cast on end in dry sand moulds. The method employed requires only one three-part moulding box and one cylindrical pattern of the same height as the mould sections, this being fitted with loose core prints. The two-part core is reinforced with 12 mm. rods and 50 mm. perforated tubes which also act as vents. Up-hill pouring is used for the smaller rolls, typical pouring time being 80 sec. for a 4½-ton roll.—G. G. K.

**Casting Heavy "Ilgner" Fly Wheels.** V. Batěk. (*Slévárenství*, 1954, **2**, (2), 46–48). [In Czech]. The origins of the most frequent types of faults in large flywheel castings, such as cracks and porosity, are traced and correct methods of casting and mould design are indicated.—P. F.

**The Production of Chill Castings in Permanent Cast Iron Moulds.** F. Naumann. (*Met. u. Giesserei Techn.*, 1954, **4**, Mar., 118–124). The process described has now passed the experimental stage, and is suitable for simple castings as well as for complicated ones such as Diesel injection pumps.

**Castings for Gas Turbines.** (*Aeroplane*, 1954, **86**, Feb., 185–186). The production of heat-resisting castings for use in gas turbines by Sheepbridge Steel Castings Ltd. is described. Centrifugal and shell moulding methods are the principal ones used and a large range of alloys are handled.

**Study of Investment Casting (II).** T. Mishima, Y. Mishima, and K. Kobayashi. (*Annual Report Engineering Res. Inst., Toyko University*, 1953, Dec., No. 12, 63–65). [In Japanese]. The thermal expansions of both natural and fused silica, and the dimensional change of cast metal parts were measured. The dimensional change is affected not only by the kind of materials used but also by the grain size distribution of the sand and the amount of binder. A sand of desired thermal expansion can be obtained by mining natural and fused sands in suitable proportions.—L. E. W.

**Molecular Bonded Bimetallic Components.** (*Engineer*, 1954, **197**, Mar. 12, 387–389). A process of bonding aluminium to iron and other metals as performed at the Lymington works of Wellworthy Ltd. is described. It is called the "All-Fin" process as it is used to bond aluminium fins on to aircraft engine cylinders. There are three stages: (1) The non-aluminium part is chemically cleaned; (2) the cleaned part is aluminized to form a complex layer of ferrous nitrides on the surface; and (3) the treated part with the surface still molten is placed in a mould or die and the mould is filled up with aluminium. The process is essentially a foundry operation.

**The Fordath D-Process.** (*Machinery*, 1954, **84**, Mar. 5, 501–505). The article describes experimental work carried out by the Fordath Engineering Co. (Staffs.) on the development of a quick drying oil and on a new method of blowing shell moulds, with a view to applying the process for production of castings on a large scale.—M. A. K.

**Continuous Casting of Iron Bar.** (*Machinery*, 1954, **84**, Mar. 5, 506–507). The article describes the production methods employed by Harold Andrews Grinding Co. Ltd. in the continuous casting of iron bar. The process, known as 'Flocast,' enables sound bars, free from sand inclusions and blowholes, to be obtained in a range of dimensions from ⅞ to 3 in. in dia., up to 8 ft. long.—M. A. K.

**Coleman-Wallwork Shell Mould Clamping Device.** (*Machinery*, 1954, **84**, Jan. 29, 227). A new clamping device for the rapid assembly of shell moulds, which has been developed by Coleman-Wallwork Co. Ltd. is described. The device has been employed for fastening together with considerable success. Pressure can be applied to any specific area and it is claimed that the use of these clamps will largely eliminate flash caused by gaping of the mould faces.—M. A. K.

**Centrifugal Casting of Iron Pipes.** (*Engineering*, 1954, **177**, Mar. 12, 345–346). A brief description is given of a German centrifugal casting machine for iron pipes, built by Ardeltwerke G.m.b.H., Wilhelmshaven. Its hourly production rate is claimed to be up to 40 cast-iron pipes 4 in. in dia. and 6 ft. 6 in. long.—M. D. J. B.

**Mercast Valve Body Shows How Booking Allows More Design Latitude.** (*Precision Met. Molding.*, 1954, **12**, Jan., 40–42). The article describes the manufacture of a valve body by the investment casting process using frozen mercury as the pattern. The booking process, which entails the casting of two halves of the pattern in mercury and joining them together, is fully explained.—D. H.

**Melting Practice for Investment Casting.** S. Tour. (*Precision Met. Mold.*, 1953, **11**, Oct., 64–65; Nov., 40–41). The author discusses briefly the raw materials and melting equipment used in investment casting.—D. H.

**Control in an Investment Foundry.** D. F. B. Tedds. (*Found. Trade J.*, 1954, **96**, Jan. 14, 37–42; Jan. 21, 77–82). A detailed description, with particular emphasis on the process control methods employed, is given of the lay-out and operation of the precision investment foundry attached to the Bristol Aeroplane Co. Ltd. The patterns are produced by injection in fully automatic machines, built up into casting formation using electrically heated spatulas, and then coated with alumina cement before the final investment process. Each mould is clamped to the top of a furnace and the metal poured by inverting the assembly. A development section of the foundry initially investigates each component and develops methods for its successful production. It is only by a high degree of supervision and control that successful quantity production is possible.—B. C. W.

**Casting Agricultural Machinery Gears in Shell Moulds.** (*Machinery*, 1954, **84**, Jan. 29, 211–216). Methods employed by Thomas Blackburn and Son Ltd. in the casting of gears in shell moulds for Ferguson agricultural machinery are described. The article discusses the problems encountered in the manufacture of the shells and assembly of the moulds. The necessary machining requirements and the system of inspection adopted are also described.—M. A. K.

**Practical Experience of Shell Moulding.** C. Potter. (Inst. Brit. Foundrymen: *Found. Trade J.*, 1953, **95**, Dec. 24, 783–785). The author briefly discusses his experiences with the shell moulding process and reviews some of the difficulties that have been overcome. With shell moulded castings the greatest saving in costs is not achieved in the foundry but in the machine shop.—B. C. W.

**The Mechanical Clamping of Shell Moulds.** D. A. Taylor. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1953, **4**, June, 568–570). A new method, developed by B.C.I.R.A., of joining the two halves of a shell mould when poured vertically, is described.

**Partial Mechanization Gives High Output in Small Area.** (*Amer. Foundryman*, 1954, **25**, Jan., 36–39). A description is given of the mechanized stack moulding section of the foundry of Cutler-Hammer Inc., Milwaukee, together with details of the processes employed.—B. C. W.

**All-Electric Operation Features Modern Permanent Magnet Foundry.** R. H. Herrmann. (*Foundry*, 1954, **82**, Jan., 86–91, 206, 208, 210, 212). A detailed description is given of the new permanent magnet foundry of the Carboloy Dept., General Electric Co., Edmore, Michigan. The magnets are cast in stack moulds with clusters fed from a central sprue by radial runners and slot gates. After shake-out and rough grinding, the castings are heat-treated and cooled in a magnetic field so as to align the magnetic domains. This treatment is followed by ageing at 600° C., air-cooling, demagnetizing, and sand-blasting. The castings are finally ground to size, cleaned, and tested. Test bars taken from each heat ensure that sub-standard castings are rejected before any work has been done on them. The heat-treatment furnaces include three with molybdenum windings operating in atmospheres of hydrogen.—B. C. W.

**Modern Swiss Foundry Incorporates Automatic Controls.** V. Frey. (*Foundry*, 1954, **82**, Jan., 104–109). The recently modified foundry of Escher Wyss Ltd., Zürich, now includes a fully mechanized and automatic sand preparation and distribution system. This system supplies four kinds of moulding sand and deals with three types of shake-out sand. The

entire sand preparation plant is controlled from a central switchboard and a block system of control ensures that operations are always carried out in the correct order.—B. C. W.

**Rational Foundry Management.** F. Buckley. (*Found. Trade J.*, 1954, **96**, Jan. 21, 63–69; Jan. 28, 103–106). Between 1945 and 1949 the heavy jobbing foundry of the English Electric Co. Ltd. was reorganized to enable casting production to be expanded by 2½ times with little or no increase in the labour force or in the size of the buildings. Where possible moulding is done on machines or in boxes, and the lay-out of the foundry is arranged to facilitate a logical sequence of operations from moulding to knock-out. The installation of expensive equipment in jobbing foundries is no guarantee of increased productivity unless it is accompanied by a revolutionary change of attitude on the part of the foundry executives.—B. C. W.

**Some Examples of Moulding Floors Arranged for Discontinuous Casting with the Handling of Moulds on Roller Conveyors and Wheeled Trays.** L. Bigard. (*Fonderie*, 1953, Sept., 3599–3612). A detailed description is given of various types of mould conveyors and possible arrangements for storage, knock-out, and return are discussed. All the lay-outs are for foundries where the casting is discontinuous.

**Roughness of Metal Castings.** C. Dias Brosch. (*Bol. Assoc. Brasil. Met.*, 1953, **9**, July, 344–365). [In Portuguese]. The roughness of castings is of importance from the point of view of appearance, finishing operations, and tolerance. The factors affecting the evaluation of roughness are classified. Roughness can be controlled by the casting temperature, the thermal conductivity of the sand, and the grain size of the sand and blacking. A method of specifying the degrees of roughness of castings is proposed.—R. S.

**Incorrect Mould and Core Making as Causes of Defects in Iron Castings.** P. Januszewicz. (*Przeglad Odlewnictwa*, 1954, **4**, (2), 30–39). [In Polish]. Errors in different stages of production which may cause defects in castings are discussed.

**Influence of the Quality of Molten Iron on Defects in Castings.** C. Kalata. (*Przeglad Odlewnictwa*, 1954, **4**, (1), 9–14). [In Polish]. The influence of iron quality on the defects in castings are discussed and the following factors are considered: Chemical composition, melting temperature, amount and method of making alloying additions, method of inoculation, and casting temperature.—V. G.

**The Classification of Defects in Grey Iron Castings.** M. Czyzewski. (*Przeglad Odlewnictwa*, 1954, **4**, (1), 4–5). [In Polish]. A classification of defects in grey iron castings is given and the factors on which it is based are discussed.—V. G.

**Several Factors Influence Linear Shrinkage.** H. Chappie. (*Foundry*, 1954, **82**, Jan., 100–103). The shrinkage of a casting after solidification is influenced by casting design, method of moulding, type of moulding sand, and amount of ramming. This means that no fixed rule can be used to estimate shrinkage on patterns, and accumulated experience is the best guide.—B. C. W.

**Impregnation of Metal Castings.** (*Found. Trade J.*, 1954, **96**, Jan. 28, 107–108). A review is given of the methods and materials available for impregnating porous castings in order to ensure pressure tightness. The processes are only effective when the leaks are small and should only be used to compensate for unfavourable design or limitations in casting techniques.—B. C. W.

**Quality Control in the Foundry.** J. M. Barabee. (*Amer. Foundryman*, 1954, **25**, Jan., 50–54). Some of the quality control methods used in the foundries of the International Harvester Co., are described and examples are given of the results achieved with them. Wherever possible the records are expressed by charts so that the significance of the data can be readily perceived. Average and range charts are used for controlling the temperature and composition of cupola metal, the uniform charging of the cupola, and the pouring rate of moulds. Charts showing percentages of defects are used for recording defective cores and moulds, and frequency distributions for giving an overall picture of a process.—B. C. W.

**Statistical Quality Control.** A. J. Kukla. (*Foundry*, 1953, **81**, Dec., 120–124, 248–249). The application of statistical quality control to sand foundries is discussed and examples are given of the results achieved in a magnesium foundry. The statistical data were expressed in simple graphs based on the average and range charts or percentage defective charts. The best results were obtained by posting diagrams which showed the relative performances of the various shifts.

**Co-Operative Safety Programme Produces Outstanding Record.** (*Amer. Foundryman*, 1954, **25**, Jan., 44–48). Details are given of the safety programme in force at the Eaton Manufacturing Company's foundry at Vassor, Michigan, which in six years has reduced the accident frequency rate by 50% and the severity rate by 98%. The programme is based on the theory that health and safety are a necessary and integral part of business just as is production.—B. C. W.

**Educating Management to a Valuable Tool.** J. Taylor. (*Amer. Found. Soc. Preprint*, 16, 1954). It is shown that time-study data and a combined data and job specification sheet have uses in a foundry in addition to that of computing incentive wages.—R. A. R.

**An Incentive Plan for "Line" Supervisors.** E. D. Bolden. (*Amer. Found. Soc. Preprint* 47, 1954). An incentive bonus scheme for men in the category of foreman, leading hand, and supervisor in a foundry is outlined.—R. A. R.

## HEATING FURNACES AND SOAKING PITS

**Industrial Furnaces: Heating for Hot Forming.** (*Iron Age*, 1954, **173**, Feb. 25, F28–F46). Reheating furnace installations for many types of large and small forgings are described.

**Heat Processing in Industry—Facts and Figures.** F. O. Hess. (*Iron Steel Eng.*, 1954, **31**, Feb., 73–84). A description is given of some fundamental concepts of industrial heating requirements. Only fuel-fired processes and equipment are considered. Heat transfer by convection and radiation, types of furnace, heating techniques, and the effects these have on steels are discussd.—M. D. J. B.

**Heat Transfer in a Continuous Reheating Furnace.** R. J. Sarjant and D. Smith. (*J. Inst. Fuel*, 1954, **27**, Jan., 16–24). The results are presented of tests on an experimental furnace designed to simulate the working conditions of a continuous reheating furnace. Suitable methods of calculating the heat transmission are discussed and it is concluded that sectional calculations are required with particular attention to radiant effects between sections.—D. L. C. P.

**Pusher Type Furnaces.** E. W. Weaver. (*Metal Treating*, 1953, **4**, Sept.-Oct., 6–8). The design of pusher furnaces is considered with reference to (*a*) type of drive, and (*b*) method of charging. Hydraulic and air cylinders, and electrically operated rack and pinion and rocker arm assemblies are described in connection with (*a*), whilst overhead handling, the use of baskets and trays, and direct piece-to-piece contact are discussed under (*b*).—P. M. C.

**Roller Hearth Furnaces.** C. O. Knierim. (*Metal Treating*, 1953, **4**, Sept.-Oct., 9, 10). Brief details are presented of the general design and uses of roller hearth furnaces. By employing silicon carbide rollers mounted on water-cooled shafts such furnaces can operate at temperatures up to 2600° F.

**Rapid Heating of Semi-Finished Products.** H. Wübbenhorst. (*Stahl u. Eisen*, 1954, **74**, Mar. 25, 420–421). Some recent developments in the U.S.A. in the construction of rapid heating furnaces, fitted with radiant gas burners, are reviewed. The high heat transfer coefficient makes possible a very high through-put.—J. P.

**Studies on the Scaling of Slabs, etc.** M. Shidera and K. Okada. (*Tetsu to Hagane*, 1950, **36**, June, 252–255). [In Japanese]. A formula is given for calculating the amount of scale on slabs, billets, and blooms. Analyses and heats of oxidation of scale are given.—K. E. J.

**Consett Iron Company Limited: Soaking Pits.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 58–60). The Consett soaking-pit installation comprises 12 one-way-fired Stein and Atkinson pits, 25 ft. × 8 ft., with air and blast-furnace gas preheated by the Austeel-Escher recuperation system. The coke-breeze bottoms have no provision for bottom-dumping. Details of design and operation are outlined.—G. F.

**Consett Iron Company Limited: Continuous Slab-Heating Furnaces.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 60–61). Two Rust end-discharge slab reheating furnaces have been installed at the Consett Iron Co., Ltd. Brief details are given of the plant, including the automatic furnace control.—G. F.

**Induction Heating: Low Frequencies Have Advantages.** J. A. Logan. (*Iron Age*, 1953, **172**, Dec. 24, 69–72). The application of induction heating to billets is described. Coil designs are now available for operation at mains frequency eliminating motor-generator sets. Flux leakage at the ends of the billet can be corrected and a uniform flux pattern

provided. Steel billets 6 in. in dia. can be heated uniformly to 2300° F. in 5 min. with accurate temperature control.

## HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

**Pusher-Chain Conveyor Combined in Semi-Continuous Production Unit.** H. N. Ipsen. (*Metal Treating*, 1953, **4,** Nov.-Dec., 8, 9). A semi-continuous, automatic, controlled atmosphere hardening furnace with built-in quench tank is described and illustrated. The unit has an output of 800 lb./hr. and is electrically heated. Two heating chambers, separated by an inner door, are employed. A pusher mechanism, when activated, loads the first chamber and at the same time transfers the previous charge from the first to the second chamber. The work is transferred into the quench tank by two alloy steel chains.—P. M. C.

**Conveyorized Hardening Furnaces.** A. J. Jarema. (*Metal Treating*, 1953, **4,** Nov.-Dec., 6, 7, 30). A general appraisal and description of modern mechanized hardening, quenching, and tempering installations is presented. The complete elimination of scaling and decarburization by the use of protective atmospheres and the high efficiency of electrically heated furnaces are emphasized.—P. M. C.

**Salt Baths—Versatile Performers on the Heat Treating Team.** L. B. Rosseau. (*Steel*, 1954, **134,** Feb. 15, 108–111). A general review of the characteristics of salt baths for heat-treatment purposes is presented. Their application to modern production methods is illustrated.—D. L. C. P.

**Industrial Furnaces: Surface Treating and Hardening—Controlled Heating and Cooling.** (*Iron Age*, 1954, **173,** Feb. 25, F4–F18). A series of very short articles is presented containing descriptions and illustrations of furnaces and installations for heat-treating a variety of large and small parts.

**Temperature Ranges—Industrial Heating Operations.** (*Iron Age*, 1954, **173,** Feb. 25, F70–F72). A table, set up in alphabetical order of the metals and alloys, gives the melting point and appropriate temperatures for a wide variety of industrial processes including heat-treatments, forging, drawing, rolling, and welding.—R. A. R.

**Glossary of Heat Treating and Testing Terms.** (*Iron Age*, 1954, **173,** Feb. 25, F50–F69). A short glossary compiled by the Bethlehem Steel Company is presented.—R. A. R.

**The Heat-Treatment of High-Carbon, High-Chromium Tool Steel.** J. Lomas. (*Machinery Lloyd*, 1954, **26,** Mar. 20, 65–68). The author discusses briefly the procedure and precautions to be observed in the heat-treatment of a typical high-carbon, high-chromium tool steel. The steel is usually hardened by heating to 100–120° C. above its critical point after heating slowly to 800° C. The temperature should never exceed 1100° C. and ample time at the forging temperature before manipulation is recommended. Hot working should not be continued below 950° C. and when completed the steel should be normalized and fully annealed.—L. E. W.

**Razor Blade Test for Decarb.** (*Steel*, 1954, **134,** Feb. 1, 91). A simple method is suggested for testing the decarburizing properties of a salt bath. A razor blade after immersion for a standard time will bend without snapping if the bath needs attention.—D. L. C. P.

**Flame Hardening and Its Application to Meehanite Metal.** R. Ekins. (*Metal Treating*, 1953, **4,** Sept.-Oct., 4, 5). A new type of gas orifice for flame-hardening torches is illustrated. The neck of the orifice is closed in, thus increasing the gas velocity above that of the flame velocity, and prohibiting the propagation of the flame back into the torch and mixture. This enables 'in-line' orifices to be used, instead of the previous staggered arrangement, and greater flame concentration in a narrower heat band is obtained. Some observations on the flame hardening of Meehanite Metal using this torch are presented.—P. M. C.

**The Applications of British Industrial High-Frequency Heating Equipment.** (Third International Congress on Electro-Heat : *Beama J.*, 1954, **61,** Feb., 38–50). The applications of induction heating to, and the types of power units required for, melting, through-heating, surface hardening, brazing, soldering, and vacuum techniques, are dealt with. Dielectric heating is also considered in relation to plastic preheating and welding, furniture manufacture, foundry cores, etc.—L. E. W.

**Heat-Treatment of Rails.** J. Koutský. (*Hutník*, (Prague), 1953, **3,** (11), 252–254). [In Czech]. Some Czechoslovakian and Russian experiences on the heat-treatment and optimum composition of rails are discussed. High-frequency equipment, operating at 500 kilocycles/sec., used for heat-treating rails and sorbitizing rail ends is described. Depth of hardening, the relation between hardness and brittleness in rails, flakes and related problems are considered.—P. F.

**Carbo-Nitriding.** (*Automobile Eng.*, 1953, **43,** Dec., 550–552). A new Birlec controlled atmosphere furnace for light-case work is fully described and illustrated. The development is the outcome of a manufacturing agreement with the Dow Furnace Co., U.S.A. An important innovation is the incorporation of catalytic gas generators of the endothermic type within the radiant heating tubes, thus eliminating the need for the more usual separate generator. The furnace is of the horizontal batch type with integral quench tank, and will process loads up to 600 lb. Operating costs are claimed to be only 40–50% of those of liquid cyanide baths.—P. M. C.

**Nitriding of Austenitic Steels.** K. S. Khomenko. (*Vestnik Mashinostroeniya*, 1952, **32,** (3), 71–72). The influence of surface treatment, type of furnace, ammonia concentration and heating rate on the nitriding of specimens of steels, 1KH18N9T (0·1% C, 18% Cr, 9% Ni, plus titanium) and 4KH14N14V2M (0·4% C, 14% Cr, 14% Ni, 2% W, plus molybdenum) was investigated. On the basis of experimental data the nitriding procedure giving best results is recommended.—V. G.

**The Use of Hot Face Insulation in Large Annealing Furnaces.** (*Indust. Gas*, 1953, **17,** Nov., 54–60). The paper reports the results of a five-day trial under normal working conditions on two similar gas-fired batch-type annealing furnaces, one lined with hot face insulating material, the other with firebrick backed by insulating refractory. Owing to the lower thermal capacity and conductivity of the insulating refractory, the furnace using it came up to temperature more quickly, maintained temperature with less gas, and cooled down more slowly than the other furnace. The main advantages of hot face insulation are obtained in short-time batch treatments.

**Annealing or Softening Improves Grey Iron Machinability.** C. O. Burgess. (Gray Iron Founders' Soc. : *Foundry*, 1953, **81,** Dec., 108–111, 250 ; 1954, **82,** Jan., 110–113). Results are given to show that grey iron machines most easily when the microstructure is ferrite-graphite, and the annealing treatments used to produce this structure are considered in detail. In general, an annealing temperature of 1400° F. (760° C.) will be satisfactory, but to remove chilled spots the temperature may be raised to 1720° F. (945° C.). If annealing is carried out above 1450° F. (788° C.) the casting should be slowly cooled through the transformation range to prevent the formation of pearlite. The effects of alloying elements on carbide stabilization are briefly considered.—B. C. W.

**Short-Cycle Hardening of Tool Steels.** J. Y. Riedel. (*Metal Treating*, 1953, **4,** Sept.-Oct., 2, 3, 26). Experiments are described, the aim of which was to develop procedures for hardening certain tool steels in less time than in conventional practice. For 1 in. round bar of high-carbon high-chromium steel, a suitable short time cycle is : (*a*) Preheat to 1500° F. (45 min. at temperature), (*b*) heat to 2100° F. (5½ min. in furnace), (*c*) air cool to room temperature, (*d*) subzero chill in liquid nitrogen (1 hr.), and (*e*) temper to desired hardness (usually Rockwell C 60). The subzero chilling, which may be impracticable, may be replaced by tempering at 1000° F. for 2 hr. S.A.E. D3-type steel (also high-carbon high-chromium) also responds to the treatments outlined above. A 5%-Cr air-hardening type will only give a hardness of Rockwell C60 if subjected to the subzero chill.—P. M. C.

**Hot Oil Quenching Toughens Tractor Shovel Parts.** R. H. Marshall. (*Iron Age*, 1953, **172,** Dec. 31, 67–71). Tractor shovels by repeated back and forth movement in service subject gears and other parts to intermittent peak stress loads. To meet these conditions the parts are quenched in oil at 300° F. after carburizing. Sliding parts receive a thin hard case by dry cyaniding. Claims of increased production and reduced cost are made.—A. M. F.

## FORGING, STAMPING, DRAWING, AND PRESSING

**The Manufacture of Bolts and Nuts in South Africa.** A. D. Mitchell. (*J. S. African Inst. Mech. Eng.*, 1953, **3,** Aug., 3–16). The author discusses the hot, semi-hot, and cold methods of forging for bolts, nuts, and rivets.—L. E. W.

**Rod and Wire Quality vs. Cold Heading Quality.** W. E. Hill, jun. (*Wire and Wire Prod.*, 1953, **28,** Dec., 1291–1293, 1357–

1359). Defects encountered in cold headed products are described and their causes examined. Each defect is illustrated. The causes include faulty material and faulty manufacture.—J. G. W.

**Automatic Machine for the Manufacture of Studs and Similar Components from Wire Stock.** W. Moeltzner. (*Draht, English Ed.*, 1953, June, 24–26). The machine and its principle of operation are described in detail and some manufacturing costs are quoted for German conditions.—J. G. W.

**Significance and Scope of Rough Forging.** F. Drastík. (*Hutník*, (Prague), 1954, **4,** (1), 11–14). [In Czech]. Methods and principles involved in correct rough-forging of components such as poppet valves, connecting rods, and crankshafts, as a preliminary to finishing in dies, are discussed. Higher product quality, greater economy in production and longer life of dies should result from correct use and from the improvements suggested.—P. F.

**Heavy Forging Presses.** A. Zeitlin. (*Aircraft Prod.*, 1954, **16,** Feb., 53–58). A review of developments in the design, construction, and uses of heavy forging presses in the U.S.A., is presented. The presses are for use in forging aircraft parts. The largest presses to be installed in America in the near future will be two of 50,000 tons and two of 35,000 tons ; the largest press at present operating is of 18,000 tons.—B. G. B.

**The Hot Shaping of Metals.** E. Siebel. (*Z. Metallkunde*, 1954, **45,** Jan., 1–7). A general survey is made of the mechanism and methods employed in the hot working of ferrous and non-ferrous metals and alloys.—L. D. H.

**Drop Forging Hammers.** W. Wróblewski. (*Hutnik* (Poland), 1954, **21,** (2), 41–48). [In Polish]. Descriptions of several drop forging hammers and their fields of application are given.—V. G.

**Report of the Committee on Conditions in the Drop-Forging Industry.** (*Metal Treatment and Drop Forging*, 1953, **20,** Dec., 594–596). A brief review is presented of the main conclusions and recommendations of the Committee, appointed in June 1951 by H.M. Chief Inspector of Factories, to consider the working conditions in the drop-forging industry in respect of the safety, health, and welfare of employees. The Committee's report, which has been published as a White Paper, deals with buildings, cleanliness, safety, handling of materials, and welfare.—P. M. C.

**Aero Industry Eager to Christen Monster Presses.** J. R. Douslin. (*S.A.E. J.*, 1953, **61,** Oct., 49–54). The abridged proceedings, in question and answer form, of the April 1953 meeting of the S.A.E. Aeronautic Production Form Panel on Large Forgings and Castings, are reported. Information is presented on the uses, products, tooling, and economics of the eight heavy presses which are nearing completion under the U.S.A.F. Heavy Press Programme.—P. M. C.

**Hydraulic Accumulators.** E. M. Greer. (*Machine Design*, 1953, **25,** Nov., 140–141 ; Dec., 248–249 ; 1954, **26,** Jan., 132–135). The author briefly describes the principles and uses of hydraulic accumulators. Gases which have a high degree of compressibility are combined with liquids in controlled volumes within an enclosed vessel under controlled pressures, this produces a hydropneumatic accumulator whose dynamic energy can be utilized to do useful work.—M. A. K.

**Control Valves for Direct-Hydraulic Presses.** F. H. Towler and J. M. Towler. (*Proc. Inst. Mech. Eng.*, 1952–53, **1B,** (9), 420–427). A completely new hydraulic control system which eliminates all electrical controls is described. The paper deals with packingless piston valves, the avoidance of various forms of lock, and the problems involved in the design, construction and control of large hydraulic presses, the choice of the most advantageous working pressure, and the viscosity of the hydraulic oil. A detailed description is given of a 1000-ton direct hydraulic forging and planishing press, powered by high-speed pumps totalling 665 pump h.p. and controlled by a single lever, completely hydraulic, remote control panel. The press makes reversals in 0·1 sec. Controls and multiple power units for much larger presses are discussed. (11 references).—P. M. C.

**The State of Development of Hydraulic Presses for the Manufacture of Semi-Finished Metal Goods.** W. Geiger. (*Z. Metallkunde*, 1954, **45,** Jan., 48–54). A survey is given of the present state of development of hydraulic presses of various types in Germany and the U.S.A.—L. D. H.

**New Points of View on Guards for Presses.** F. Schaffer. (*Maschinenwelt u. Electrotechnik*, 1954, **9,** Feb., 43–46). Modern methods for the protection of press operators are discussed in detail.—L. D. H.

**Equipment Tailored for New-Plant Jobs.** (*Steel*, 1954, **134,** Feb. 1, 128–129). A brief description is given of the new plant of the Foster Wheeler Corp., for producing pressure vessels. The 8000-ton hydraulic beam press will bend 8-in. hot steel plate.—D. L. C. P.

**Handling Swarf and Press Scrap at AC-Delco.** (*Machine Shop Mag.*, 1954, **15,** Mar., 102–108). The article describes two entirely separate plants installed at AC-Delco Division of General Motors for handling 60 tons of press scrap and 25 tons of swarf per week. In both plants, conveyors installed below floor level transport the waste material from the machines to a point where it is elevated and stored in hoppers before its removal by lorries.—M. A. K.

**Sheet Steel Drawability Measured by New Technique.** C. B. Buker and J. R. Speer. (*S.A.E. J.*, 1953, **61,** Oct., 24, 25). Two simple dial gauge instruments are described and illustrated—a Flex-tester and a simple spherometer. The former determines the force required to bend a corner of a steel sheet through a given arc and indicates the drawing quality. The spherometer measures the maximum curvature of the bend, and indicates the tendency to form stretcher strains.—P. M. C.

**How to Make Plastic Draw Dies in 9 Steps.** G. C. Adams. (*S.A.E. J.*, 1953, **61,** Nov., 21–25). The production of drawing dies in phenolic resin for sheet metal forming operations is described and illustrated diagramatically. The sequence of operations is : Make a splash plaster casting of the master punch ; cast the plastic punch ; build a binder ring model ; make a steel weldment for the binder ring ; join binder ring to weldment ; build up the punch face with wax or spray paint to the thickness of the sheet to be ultimately drawn ; prepare the steel die tub ; insert faced punch and cast the female half of the die ; and test the completed tool.—P. M. C.

**Extrusion of Alloy Steels: New 1,150 ton Loewy Press at Low Moor Fine Steels Ltd.** (*Brit. Steelmaker*, 1954, **20,** Feb., 60–62). A description is given of the horizontal hydraulic press installed at the works of Low Moor Fine Steels Ltd. for the commercial production of alloy steel extrusions. The plant has been designed and built by Loewy Engineering Co. Ltd. and employs the Ugine-Sejournet process.—G. F.

**Hot Extrusion: New Family of Uses.** (*Iron Age*, 1954, **173,** Jan. 21, 43). A modified Ugine-Sejournet process for hot extrusion of steel with glass as a lubricant uses a closed die. The billet is forced in and a ram squeezes it back over the mandrel. Anticipated products are high pressure containers and items requiring short tubular lengths with precise tolerances.—A. M. F.

**Wire Stock Reels.** W. Aumann. (*Draht, English ed.*, 1954, Feb., 26–29). Constructional details and design calculations for spools and reels for wire are presented.—J. G. W.

**The Graphical Representation of the Drawing Process in the Drawing of Wire on Multiple Wire-Drawing Machines, with Special References to Slip Accumulation, and Die Wear.** F. Liekmeier. (*Draht, English ed.*, 1954, Feb., 15–18). Graphical representations of the multihole drawing process based on the constancy of volume in metal working are described. The representation on speed/diameter graphs of the effects of slip and accumulation and of die wear is explained.—J. G. W.

**Electric Motors and Control for Slip Type Wire Drawing Machines.** H. A. Dickerson. (*Wire and Wire Products*, 1953, **28,** Dec., 1295–1304, 1334–1343).

**A High-Speed Non-Slip Accumulation Wire-Drawing Machine.** N. Davidson. (*Wire Ind.*, 1954, **21,** Mar., 275–277). A new wire-drawing machine, manufactured by Sir James Farmer Norton & Co., is described, which is said to combine the ability to cool wire with the absence of twisting peculiar to high-speed 'straight-line' capstan machines. Instead of overhead take-off *via* rotating area and pulley, the wire is accumulated on an outer block concentric with the drawing block.—J. G. W.

**Cemented Carbide Drawing Dies for Iron and Steel Wire.** H. Wedl. (*Draht, English ed.*, 1953, June, 38–45). Production of sintered carbide pellets, standardization and die design, causes of die wear, maintenance and reconditioning, inspecting methods, and instruments are described and discussed.

**A Practical Analysis of the Causes of Die Wear in the Dry-Drawing of Ferrous Wires.** E. P. Riley-Gledhill. (Frederick Smith and Co., Wire Manufacturers Ltd., Mar. 24, 1954). After tracing the development of wire-drawing the author

examines in detail the modern techniques. In reviewing the sequence of events within dies when excessive wear takes place, particular reference is made to the included drawing angle, rod coating-media, lubricants, and the efficient cooling of the dies and wire. The methods generally adopted to overcome excessive wear are outlined. The author concludes that : (1) Excessive die wear may be eliminated through the correct alignment of ingoing wire and dies ; (2) when misalignment exists the presence of a sull or phosphate coating does not prevent excessive die wear ; (3) perfect alignment of the ingoing wire produces the least and most uniform drawing ring ; and (4) misalignment of outgoing wire shows no marked detrimental effect on the die.—L. E. W.

**Measuring Instruments for Determining the Thickness of Wire.** Sachs. (*Draht, English ed.*, 1954, Feb., 32–33). 'Slipping' micrometers of German manufacture for gauging moving wire are described and illustrated.—J. G. W.

## ROLLING-MILL PRACTICE

**General and Structural Developments in the Construction of Modern Metal Rolling Mills.** E. H. Barten. (*Z. Metallkunde*, 1954, **45**, Feb., 57–66). Modern developments in the design and construction of rolling mills for the non-ferrous metal industry, and their ancillary equipment, are described in detail and fully illustrated.—L. D. H.

**Study in the Industrial Instrument for Continuous Rolling Mill.** M. Oyama and Y. Nozaka. (*Annual Report Engineering Res. Inst., Tokyo University*, 1953, Dec., No. 12, 102–104). [In Japanese]. The authors discuss the development of a width gauge for a high-speed hot-strip mill. The direct coupled D.C. amplifier was unsuitable and a description is given of a gauge in which an A.C. amplifier is used in conjunction with a rotary disc for efficient amplification of the photo-electric current.—L. E. W.

**Calculation of Roll Force and Torque in Cold-Rolling by Graphical and Experimental Methods.** R. B. Sims. (*J. Iron Steel Inst.*, 1954, **178**, Sept., 19–34). [This issue].

**Study on the Detection of Internal Flaws of Mill Rolls by Means of Ultrasonic Waves.** M. Oyama and Y. Nozaka. (*Annual Report Engineering Res. Inst., Tokyo University*, 1953, Dec., No. 12, 99–101). [In Japanese]. The testing of rolls at the Yawata Iron and Steel Co. by ultrasonic waves is described, and illustrated by typical results. The ultrasonic inspection was satisfactory for the production, maintenance, and reception of rolls.—L. E. W.

**A Contribution to the Reduction of Mill Roll Failures.** R. Springer. (*Met. u. Giesserei Techn.*, 1954, **4**, Jan., 23–24). Having investigated bending stresses in cast-iron rolls, the author proposes to reduce failures by changing the continuous curve of the fillet between roll barrel and neck so that the contour has straight portion with a short curve at each end.

**Consett Iron Company Limited: Plate Mills.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 62). A very brief description is given of the two plate mills and the plate shears installed in accordance with the reconstruction programme.—G. F.

**Consett Iron Company Limited: The New Rolling Mills.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 63–71, 104). The new rolling-mill plant of this company comprises a high-lift blooming and slabbing mill, followed by a Morgan continuous billet and slab mill in two groups of six and four stands respectively. The sections are arranged for straight-line delivery, one to another, without the necessity for reheating. Each section, and particularly the blooming and slabbing mill, is described in detail.—G. F.

**Consett Iron Company Limited: Lubrication of Slabbing and Blooming and Continuous Billet Mills.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 72–73). An outline is given of the lubrication systems employed on the new rolling mills and ancillary plant at the Consett Iron Co. Ltd. The lubrication requirements have been closely co-ordinated with the mill design and construction, and a layout diagram is included.—G. F.

**Consett Iron Company Limited: Electrical Equipment.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 74–80). A description is given of the electrical equipment associated with the new rolling mill plant at Consett Iron Co. Ltd. Attention is mainly given to the drives of the blooming and billet mills and cranes, and brief details are given for the auxiliaries. Lubrication and ventilation are also mentioned.

**Consett Iron Company Limited: The Jarrow Bar and Strip Mill.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 97–98, 102). The Consett Iron Co. Ltd. owns a modern merchant bar and strip mill at Jarrow, arranged to give straight-line throughput. A description is given of the roughing and finishing mills, with details of the mill drives and the mill-motor house.—G. F.

**Formation of Cracks in Rails.** J. Gorecki. (*Hutnik*) (Poland), 1954, **21**, (2), 35–41). [In Polish]. The service conditions of rails, and the causes and positions of failures are outlined. The formation of hair-line and open cracks during rolling and methods for their prevention are discussed.

**Construction and Operation of a Plate Mill in Restricted Accommodation.** F. Franke. (*Met. u. Giesserei Techn.*, 1954, **4**, Jan., 19–22). A description is given of the layout of a plate mill, including slab heating furnaces, pushers, mill tables, three-high stand, straightening machine, cooling banks, and shears, all housed on a floor area of 2350 sq. m.—L. J. L.

**Impact of Technical Developments in Light Flat Rolling on the Consuming Industries.** W. T. Hogan. (*Iron Steel Eng.*, 1954, **31**, Feb., 67–71). This paper describes technical developments in the light flat rolled section of the steel industry and evaluates the impact of these developments on the consuming industries and the economy in general.—M. D. J. B.

**Electrical Systems for Hot Strip Mills.** R. E. Marrs. (*Iron Steel Eng.*, 1954, **31**, Feb., 99–106). The author studies the electrical systems in use, or available today and reviews the contributions which the manufacturer of electric equipment can make to hot strip mill operations. These include : Width gauge, X-ray gauge, common bus voltage regulation, motor field regulators, electronic regulators, magnetic amplifiers, and mercury arc rectifiers.—M. D. J. B.

**Application and Use of Self-Centering Rolls.** E. T. Lorig. (*Iron Steel Eng.*, 1954, **31**, Jan., 59–72). The author discusses the advantages of automatic self-centering rolls for wide strip processing lines of all kinds where tracking troubles are to be encountered. The effects of strip contour variations on tracking over a series of conventional cylindrical rolls at normal tensions are described, as well as the effects of roll wear on tracking. Corrective measures are examined and the basic types of automatic self-centering rolls for automatically tracking flat strip are reviewed.—M. D. J. B.

**A Description of the Hot Rolling Mills at Iscor Works, Vanderbijl Park.** J. J. Liebenberg. (*J. S. African Inst. Mech. Eng.*, 1953, **3**, Oct., 91–114). The author describes the main features of the equipment used in the hot rolling of steel plate and strip at the Iscor Works, Vanderbijl Park (South Africa). This plant conforms to the latest practice in the continuous rolling of steel. A flow-sheet, diagrams, and photographs are included.—L. E. W.

**Control of Strip Thickness in Hot and Cold Rolling—Application of Automatic Screwdown Technique.** R. B. Sims and P. R. A. Briggs. (*Iron Coal Trades Rev.*, 1954, **168**, Mar. 5, 559–566 : *Sheet Metal Ind.*, 1954, **31**, Mar. 181–190). The authors briefly outline the advantages and disadvantages of the "tension and setting" methods of automatic gauge control, and then discuss the principles of a "screwdown control" method developed for application to the majority of existing hot and cold mills. The gaugemeter used and the control circuit are described in detail, and results are given of tests carried out to check the efficiency of the controller and to assess its performance.—G. F.

**Oils for Rolling.** A. L. H. Perry. (*Sci. Lubrication*, 1954, **6**, Feb., 14–20). Lubricants for cold rolling of metals serve to reduce friction, for cooling, to ensure uniformity of the sheet, and to give corrosion protection. Types and methods of applying oils are discussed. Applications to steel (strip, tinplate strip, stainless steel, silicon steel, and re-rolled steel) copper, brass, and aluminium are described.—K. E. J.

**Modern Methods of Seamless Steel Tube Production.** B Počta. (*Hutník*, (Prague), 1954, **4**, (2), 43–47). [In Czech]. A survey is made of methods developed and improved during the last 20 years.—P. F.

**The Dressing of Rolled Products.** Ravaudet. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (7), 1131–1148). Deformations may be accidental in origin or due to thermal gradients set up during or after rolling—only the second type is considered. The effects of thermal deformation in symmetrical and asymmetrical and in convex and concave profiles are described. Straightening may be effected by tension or flexion and the machines available are discussed.—A. G.

**On the Theory of Roll-Levelling of Sheet Bars.** T. Hayashi. (*J. Faculty of Engineering, University of Tokyo*, 1954, **24**, Jan., 45–61). [In English]. The author discusses the mechanism of levelling a sheet bar by means of a roll-leveller. Some practical data are considered and general formulæ for bending stresses and moments, and residual curvatures and stresses are derived for a sheet bar assuming perfect plasticity. The best levelling conditions for the usual type of leveller are established.—L. E. W.

**Accuracy Limitations of β-Ray Thickness Measurements.** L. Mandel. (*Brit. J. App. Phys.*, 1954, **5**, Feb., 58–64). Output fluctuations of β-ray thickness gauges impose limitations on accuracy. Theory and work on $Tl_{204}$ and $Sr_{90}$ show the relations between β-ray absorption curves and accuracy, which is not improved by collimating grids.—J. O. L.

**Establishing a System of Time Allowances for Mill Trains of a Works Rolling Special Steels.** H. Bernhardt. (*Stahl u. Eisen*, 1954, **74**, Feb. 11, 208–210). It is demonstrated how satisfactory time allowances in a rolling mill with a complicated schedule can be established even when there is insufficient time and manpower to carry out a time study on all types of rolled product.—J. P.

**Raising the Productivity of Rolling Mills.** L. Szeless. (*Kohaszati Lapok*, 1952, **7**, Jan., 1–11). [In Hungarian]. A procedure for determining the capacity of a rolling-mill, based on time studies is described.—R. A. R.

## MACHINERY FOR IRON AND STEEL PLANT

**Consett Iron Company Limited: The Power Station.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168**, Mar. 1, 81–86). The new power station at the Consett Iron Co. Ltd. provides electrical power for the whole plant, steam for the coke ovens and rolling mills, and cold blast for the blast-furnaces. Details are given of the water-tube boiler and auxiliary equipment, coal-handling plant, pulverized-fuel system, ash-handling plant, boiler control and feed-water system, power supply systems, turbo-blowers and turbo-alternators, and cooling towers.—G. F.

**Steam Generating Plant for Power Stations.** T. H. Carr. (*Mech. World*, 1953, **133**, Nov., 509–511). The author deals in detail with the important aspects of the steam generating plant. Coal handling and water treatment plants and their design and construction are mentioned. The pipe-work associated with boiler plants is also reviewed.—D. H.

**Industrial Gas Turbines.** H. N. G. Allen. (*J. S. African Inst. Mech. Eng.*, 1953, **3**, Sept., 27–65). The author discusses some of the factors affecting the choice of cycle for a given installation and emphasises the mechanical considerations peculiar to the gas turbine. Typical applications are illustrated and some of the problems still to be solved are mentioned. From these facts the influence on future trends of maximum cycle temperature is stressed. (12 references).

**6900-Volt Power System Fault Relay Analysis.** J. A. B. Pinney. (*Iron Steel Eng.*, 1954, **31**, Jan., 99–109). The author describes the latest addition to the power plant at Alan Wood Steel Co.—a 7500-kW., 6900-V., 60 cycle, extraction turbo-generator, operating from new high-pressure boilers. Details are given of a system of fault analysis designed to protect relays and to provide a minimum of interruption in the critical circuits.—M. D. J. B.

**The Use of Anti-Friction Bearings in Steelworks from the Maintenance Aspect.** H. Ponnath. (*Stahl u. Eisen*, 1954, **74**, Mar. 25, 396–402). The causes of breakdown and damage to anti-friction bearings are discussed. Methods are proposed by which regular maintenance may be applied in order to reduce costs.—J. P.

**The Performance and Maintenance of Roll-Neck Bearings at the Steel Company of Wales, Limited (Abbey Works).** H. H. Ascough and T. Jones. (*Iron Coal Trades Rev.*, 1954, **168**, Feb. 19, 445–450). The authors describe the types of roll neck bearings used in the hot and cold rolling mills at the Abbey Works of Steel Co. of Wales Ltd., discussing their performance and the maintenance required. The techniques adopted for inspection and routine maintenance are outlined, and mention is also made of the main types of bearing failure.

**42 Different Ways of Handling Steel Sections.** (*Mech. Handling*, 1954, **41**, Jan., 16–22). Different ways of gripping, lifting, and transporting steel sections are illustrated and briefly discussed.—D. H.

**The Development of the Overhead Crane as a Mechanical Handling Device.** J. Baker. (*J. S. African Inst. Mech. Eng.*, 1953, **2**, June, 306–323). The author deals with the economy of cranes, the need to instal cranes of adequate lifting capacity, comparison between heavy and light duty cranes, the need for adequate wear factor and points to be taken into consideration in planning. Diagrams are included showing special adaptions of overhead cranes. The problems faced by crane builders are outlined, and a method of grading cranes in terms of duty factors is introduced. Some of the finer points in crane design are indicated, and reference is made to a new method of calculating girder stresses. Points affecting hoist, traversing, and travelling motions are mentioned and charts are included showing a quick method of arriving at long travel motor sizes to cover varying speeds and rates of acceleration.—L. E. W.

## LUBRICANTS AND LUBRICATION

**Standardization of Lubricants in Iron and Steel Works in Germany.** (*Sci. Lubrication*, 1954, **6**, Feb., 26–27). Interior recommendations of the Committee on the Standardization of Mineral Oils and Fuels concern higher flashpoints, kinematic viscosity values, and test methods for the temperature-viscosity relationship, viscosity index, and coking value for high-temperature cylinder oils, etc.—K. E. J.

**Experiments in Hydrodynamic Lubrication Using Water as a Lubricant.** S. Abramovitz. (*J. App. Phys.*, 1953, **24**, Dec., 1521–1522). Experiments with a pivoted segmental thrust bearing have indicated an optimum convex profile for water lubrication ; the influence of a cylindrical section in reducing starting friction is dealt with.—J. O. L.

**Lubrication Problems at High Temperatures.** F. Jaklitsch. (*Maschinenbau u. Wärmewirtschaft*, 1954, **9**, Mar., 65–69). The effect of increasing temperature on the life of lubricating films is described, methods of evaluating the resistance to heat outlined, and the properties of various lubricants compared. The use of inhibitors and graphite additions are discussed, and finally the question of lubrication in machining at high temperatures is dealt with.—L. D. H.

## WELDING AND FLAME-CUTTING

**Steel Welding Research.** K. Winterton. (*Coke Gas*, 1954, **16**, Jan., 5–9). A description is given of the new fatigue laboratories of the British Welding Res. Assoc. at Abington Hall near Cambridge, and an account is given of the recent work of the Association on various aspects of steel welding particularly as it concerns the gas industries.—B. C. W.

**Developments in Welding and Cutting Processes. Important New Publications Dealing with the Electric Arc Welding Process.** (*Schweissen u. Schneiden*, 1954, **6**, Feb., 86–89). A review is given of recent literature on the arc welding process and its application to alloy steels.—U. E.

**A Fully-Automatic Welding Process.** J. Burrows. (*Overseas Eng.*, 1954, **27**, Apr., 328–330). The author discusses the application of the Lincolnweld fully-automatic welding process. A description is given of this submerged arc equipment, and general operating details are outlined. The Lincoln Twinarc method using two continuous electrodes fed from two different reels is also dealt with briefly.—L. E. W.

**Self-Adjusting Arc and Controlled-Arc Welding Processes.** W. G. Hull, and J. C. Needham. (*Welding Res.*, 1953, **7**, Aug., 80r–96r). A review is given of details and applications of the self-adjusting arc and controlled arc welding methods. The report is arranged in three parts. The first deals with fundamental features of the processes, the second is concerned with fundamental aspects such as arc characteristics and material transfer, and the third part with the information available on the welding of ferrous and non-ferrous materials.

**Effect of Nitrogen and Carbon Dioxide Atmospheres on Arc Welding.** F. W. Sowa, W. C. Truckenmiller, and L. E. Wagner. (*Welding J.*, 1953, **32**, Dec., 619s–624s). The effects of air, nitrogen, and carbon dioxide atmospheres on the physical properties and macro- and micro-structures of arc welds produced with bare and coated electrodes are studied. The significance of the adsorbed gas in the weld metal is discussed and conclusions, supported by the physical test data and micro- and macro-photographs, are drawn concerning the effect of the surrounding atmosphere on the formation, precipitation, and distribution of oxide and nitride constituents.—U. E.

**Welding for Low-Temperature Service.** R. W. Bennett. (*Welding J.*, 1953, **32**, Nov., 1089–1097). The properties of

various weld metals and base materials used in the fabrication of pressure vessels and heat exchangers for low-temperature service are discussed. For service down to −150° F. certain types of A.W.S. Class E-8016 electrodes are suitable for welding low-alloy carbon steels such as 3½%-Ni and chromium–nickel–copper steels. Fine-grained weld metal is essential for optimum notch toughness.—U. E.

**Low Temperature Bend Test Properties of Bead-on-Plate Welds.** L. A. Harris, R. B. Matthiesen, and N. M. Newmark. (*Welding J.*, 1953, **32,** Dec., 585s–599s). Studies are reported on low temperature bend test properties of notched E6010 and E6016 bead-on-plate welds subjected to various treatments. The effects of the cooling rate on embrittlement were investigated by testing welds which were water quenched after welding. The effects of preheating and postheating were also studied. The ductility of bead-on-plate welds deposited with high-hydrogen E6010 electrode notched in the weld metal is reduced by rapid low-temperature cooling rates at temperatures as low as 240° F. The weld metal deposited with the low hydrogen E6016 electrode is not subject to this embrittlement after quenching.—U. E.

**Hard Facing in the Ceramic Industries.** W. L. Lutes and H. F. Reid. (*Amer. Ceram. Soc. Bull.*, 1954, **33,** Mar., 79–82). A classification system is outlined for hard-wearing facings—weld metal overlap deposited by the metal arc welding process using coated electrodes. Application of the nomenclature in the ceramic industry is explained. The scheme, prepared by an A.S.T.M.–A.W.S. committee, gives symbols to composition-groups of the facings. Comparative values for different properties of the groups are given in a table, and typical uses of some of the groups are given.—D. L. C. P.

**Repair Welding of Ceramic-Coated Alloys.** J. M. Riordan. (*Welding J.*, 1953, **32,** Dec., 1160–1166). Welding techniques for repairing ceramic-coated structural steel parts used in aircraft have been studied, and the welds investigated microscopically. Both the inert gas-shielded arc and oxy-acetylene welding methods can be used successfully.—U. E.

**Outstanding Welding Repairs to the Base of a 5,000-Ton Press.** J. K. Mortimer. (*Welder*, 1953, **22,** Oct.-Dec., 103–107). A description is given of some welding repairs made on a 5000-ton down-stroke press the base of which was badly fractured. The fractures totalled 22 ft. in length in the base which was of cast 0·3%-carbon steel measuring 15 × 10 × 7 ft. The whole casting could not be preheated so a pattern of gas heaters was devised to give lines of heat across the area to be electric welded.—R. A. R.

**Resistance Spot Welding of $\frac{3}{16}$ in. and $\frac{1}{4}$ in. Mild Steel.** J. E. Roberts. (*Brit. Welding J.*, 1954, **1,** Mar., 136–140). Techniques for spot welding $\frac{3}{16}$ and $\frac{1}{4}$ in. thick mild steel given in previous literature are reviewed and further tests are described. These tests cover the use of electrode face angles of 30°, 20°, and 10°, with constant tip diameter for a given material thickness and electrode tip pressures of 10,000, 15,000, and 20,000 lb./sq. in. tip area, and a range of welding currents and weld times. Specific conditions for material with a smooth clean surface are recommended. The effect of material surface conditions is considerable.—U. E.

**Inert Tungsten Arc Welding of Stainless Steel Piping.** F. J. Pilia. (*Welding J.*, 1953, **32,** Dec., 1167–1174). A welding technique is described for producing interior pipe surfaces that are satisfactory for handling corrosive liquids, and high-pressure, high-temperature steam without the use of backing rings.—U. E.

**Impact Torsion Testing of Bolt Welds.** H. E. Dixon and J. E. Roberts. (*Welding Res.*, 1953, **7,** Aug., 96*r*–98*r*). The examination of metallurgical structures of bolt welds made under various welding conditions has suggested that normal methods of testing strength of welds did not discriminate sufficiently between various structural conditions such as a fully 'fused' weld or 'solid phase' weld. The impact-torsion method was therefore employed but did not reveal any difference in strength not shown by ordinary static tests.

**Investigations on Pressure Welding.** R. F. Tylecote. (*Brit. Welding J.*, 1954, **1,** Mar., 117–135). The effect of post-heat-treatment of welds has been investigated and the results are interpreted in the light of oxide film solubility and formation of intermetallic compounds. The welding of deoxidized copper in hydrogen to prevent the formation of an oxide film has also been studied.—U. E.

**Spot Welding of Low-Alloy High Tensile Steels.** P. Joumat. (*Brit. Welding J.*, 1954, **1,** Feb., 64–65). The torsion shear test is suggested as a simple and practical method of determining the quality of a heat-treated spot weld.—U. E.

**Triple-Projection Welding of Deep Drawing Mild Steel Sheet.** J. E. Roberts. (*Welding Res.*, 1953, **7,** Oct., 111*r*–114*r*). Specimen welds in 14, 16, 18 and 20 S.W.G. sheet were tested for total shear strength. Strengths equal to three times that of a single projection could be made when projections were at 2 in. pitch. At smaller pitches some reduction in the maximum strength obtainable is unavoidable. Recommended welding conditions are given.—U. E.

**Proper Technique Gives Stainless Good Weldability.** R. E. Solomon. (*Iron Age*, 1953, **172,** Dec. 10, 142–144). The basic procedures necessary to obtain satisfactory joints are described. Relatively low current, small diameter rods, and the stringer bead technique are recommended. A short arc provides better weld zone protection and results in superior corrosion resistance and appearance; preheating is good for crack-sensitive stainless steels. Major properties causing differences in technique from carbon steels are melting point, thermal conductivity, and thermal expansion.—A. M. F.

**Contribution to the Study of the Weldability of Steels.** (*Fonderie*, 1953, Oct., 3639–3652). Results are presented of a series of tests carried out to examine the weldability of both cast and wrought steels. Tensile tests were made on specimens of the same and different steels welded together, and bend tests were carried out on specimens with a line of weld metal deposited on the tension face (Dutilleul test) and on **T**-bend specimens. Among the variables investigated were composition and method of manufacture of the base steel, method of welding (arc or gas), nature of metal deposited, the effect of tempering after welding and preheating before welding, and the quality of the electrodes.—B. C. W.

**Weldability of Structural Steel.** E. L. Erickson. (*Welding J.*, 1953, **32,** Dec., 1155–1159). The weldability of structural steels, including Federal Specifications, are briefly reviewed.

**Transition Temperatures of Structural Steel Beams with Butt-Welded Splices.** W. J. Krefeld and G. B. Anderson. (*Welding J.*, 1953, **32,** Nov., 538s–576s). The investigation was primarily concerned with the strength and transition temperatures of structural steel beams, composed of semi-killed and fully killed steels and fabricated with butt-welded splices. Static and impact tests on 16-in. beams, in addition to confirming the favourable effect of aluminium deoxidation in lowering the transition temperature of the material as-rolled, indicated by Charpy tests, furnished information on the relative behaviour of two grades of steel with splices as-welded, welded and stress-relieved, and when welded with preheat.—U. E.

**Weldability of Twelve Low-Alloy Steels Containing Vanadium.** B. J. Bradstreet. (*Welding Res.*, 1953, **7,** Oct., 107*r*–110*r*). Weldability tests have been made on twelve vanadium-bearing low-alloy steel plates $\frac{5}{8}$ in. thick to determine their susceptibility to hard-zone cracking. When vanadium is present instead of molybdenum, it improves the mechanical properties of the steel. The steel which gave the best combination of weldability and mechanical properties was one containing 0·17% C, 0·7% Mn, 0·7% Ni, 0·9% Cr, and 0·22% V with a yield stress of 35 tons/sq. in. when normalized and tempered in the form of $\frac{1}{2}$ in. plate.—U. E.

**Hard-Zone Crack Sensitivity and Strength of Two Low-Alloy Steels.** C. L. M. Cottrell, J. G. Purchas, and B. J. Bradstreet. (*Welding Res.*, 1953, **7,** Aug., 76*r*–79*r*). Tests have been made on two-ton casts of two low-alloy Cr–Ni–Mo steels. Mechanical and weldability tests were carried out and the the effect of heat-treatment at various temperatures on the mechanical properties and microstructure was studied.—U. E.

**Proposal for a Classification of Weldability Tests.** H. Granjon. (*Brit. Welding J.*, 1954, **1,** Mar., 105–115). A report is given on the replies to a questionnaire on weldability tests sent to a number of countries. Data drawn from actual practice and from literature have also been included, and the principle of a systematic classification of weldability tests is proposed.—U. E.

**Testing Steels for Weldability.** R. G. Braithwaite. (*Brit. Welding J.*, 1954, **1,** Feb., 70). A simple weld bend test is recommended when dealing with a steel of unknown composition. A number of weld beads are run side by side on a piece of material using different welding techniques. The beads are machined and ground flush with the surface. The welded plate is then submitted to a bend test. Weld harden-

ing caused by pick-up of alloys from the parent metal or underbead cracking is soon revealed by premature failure.—U. E.

**The Influence of Welding Conditions on Increased Hardness at the Transition Zone of Welds in Carbon and Low-Alloy Steels.** (*Lastechn.*, 1954, **20,** Jan., 17–31). [In Dutch]. The results are reported of investigations in several laboratories in Holland, sponsored by Centrum voor Lastechniek, to ascertain the reliability of the Lehigh method of determining the increase in hardness at the transition parts of welds. This system was developed by G. E. Doan and R. D. Stout and is described in the American Welding Society's Guide to the Weldability of Steels. The results obtained are excellent and the adoption of the method is recommended. It should be used in conjunction with the Jominy test.—F. R. H.

**Strain Measurements on Welded Structures.** A. Erker. (*Schweissen u. Schneiden*, 1954, **6,** Feb., 66–69). Strain measurements were made on steel weldments. It was found that the measurements do not take into account any notch effect at undercuts. It is also necessary to apply strain gauges on both sides of sheets, girders, and sections or misleading results will be obtained. The influence of residual stresses on the measurement is discussed.—U. E.

**Manufacture of High-Grade Welded Tubes.** N. Elfström. (*Tekn. Tidskr.*, 1954, **84,** Feb. 16, 129–135). [In Swedish]. The Swedish Fagersta works, equipped with four welding lines, has an output of 20,000 tons/year of seam-welded steel tubes of all grades. After shaping the skelp in a tube-forming unit, the tube is flash-butt welded, the fins being machined off. Some problems affecting quality control are touched upon. A comparison of the relative advantages of welded and solid-drawn tubes shows that whereas in 1935 only 10% of boiler tubes were welded, the figure had risen to 32% in 1952.

**Maintenance Welding Keeps Production Moving.** W. G. Patton. (*Iron Age*, 1953, **172,** Dec. 10, 168–171). Maintenance welding at Ford's River Range plant is described.

**The Practical Advantages of Basic Covered Electrodes.** G. Zoethout. (*Prat. Soud.*, 1952, **6,** Oct., 161–165). [In French]. The advantages of using electrodes with a basic covering are discussed and examples are described where these electrodes have been used. These include welded plates of a blast-furnace, a rotary cement kiln, a 120-ton capacity multiple bogie wagon, and a welded pressure vessel.—M. D. J. B.

**Arc Welding Electrodes and Their Manufacture.** I. C. Fritz. (*Draht, English ed.*, 1954, Feb., 37–38). This is a brief survey of current types of welding electrode and the range manufactured.—J. G. W.

**Central Gas Supply.** F. Forsberg. (International Inst. Welding: *Schweissen u. Schneiden*, 1954, **6,** Feb. 85–86). Oxygen and acetylene equipment with the necessary pipelines for gas welding processes is described.—U. E.

**High-Temperature Brazing.** G. D. Cremer, F. J. Filippi, and R. S. Mueller. (*Aircraft Prod.*, 1954, **16,** Feb., 76–81). The use of a number of commercially available high temperature brazing alloys is discussed and examples of their application for corrosion resistant and heat-resistant alloys are given.

**Vaporized Flux for Bronze Welding.** (*Machinery Lloyd*, 1954, **26,** Mar. 20, 93–94). The 'Gasflux' process, developed by Weldcraft Ltd., in Surrey, is briefly described. A sketch of the equipment is included. The method is claimed to provide uniform fluxing at all temperatures, no fumes are evolved and no blow-holes are made. The flux is carried in solution in a volatile liquid which is picked up in vapour form by the acetylene in its passage to the blowpipe.—L. E. W.

**Experiences with the Oxygen Lance.** K. Boeckhaus. (*Schweissen u. Schneiden*, 1954, **6,** Mar., 102–105). The application of the oxygen lance for cutting holes into reinforced concrete sections is described.—U. E.

**Investigation of Flame Cutting Using Block Type Nozzles.** E. Zorn. (*Schweissen u. Schneiden*, 1954, **6,** Mar., 105–108). The block type nozzle is described. The nozzle is fabricated from one piece of copper and the oxygen for cutting passes through the extended middle opening which is surrounded by holes for the heating flames. The whole nozzle has a conical shape and is set into the lance and fixed with a screw. Advantages and application are discussed.—U. E.

## MACHINING AND MACHINABILITY

**Electro-Erosion Machining.** (*Aircraft Prod.*, 1954, **16,** Feb., 70–71). A description is given of a new automatic machine developed by Marbaix Industries Ltd., for producing holes in electrically conductive materials (*e.g.*, hardened steel) using the electro-erosion principle.—B. G. B.

**New Methods of Producing Thread-Cutting Dies Devised by Oldřicha Pavlovec.** M. Pospisil. (*Hutník*, (Prague), 1954, **4,** (2), 36–38). [In Czech]. The advantages of new methods of producing screwthreading dies are described. The use of cold pressing in their manufacture and improved methods of making taps are considered.—P. F.

**Efficiency and Wear of Cutting Tools.** H. Opitz. (*Maschinenwelt u. Electrotechnik*, 1954, **9,** Feb., 31–37). The laws governing the wear and efficiency of cutting tools under a variety of conditions are summarized and illustrated.—L. D. H.

**A Plastic-Flow Problem Arising in the Theory of Discontinuous Machining.** E. H. Lee. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76,** Feb., 189–194). Plastic flow is analysed adjacent to the nose of the tool in the initial stages of the formation of a discontinuous chip segment. The solution demonstrates the influence of the plastic-stress distribution in determining the process of chip forming. The variation to be expected as a result of spread of plastic flow to the initial work surface is discussed briefly. The choice between alternative types of slip-line fields which arise in certain cases is considered.—D. H.

**Discontinuous Chip Formation.** N. H. Cook, I. Finnie, and M. C. Shaw. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76,** Feb., 153–162). The characteristics and causes of the ductile, shear, and brittle types of tensile fracture are discussed and applied to the problem of chip fracture. Motion picture and dynamometer data show that completely discontinuous chip formation is entirely different from that in continuous cutting, being a periodic extrusion process rather than one of simple shear.—D. H.

**The Friction Terms in Metal Cutting.** W. C. Leone and E. Saibel. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76,** Feb., 195–198). The so-called 'machining constant' is shown to be related directly to the coefficient of internal friction, and to vary with the conditions of cutting. The coefficients of external and internal friction appear to be related to the thermal number.—D. H.

**Machinability and Microstructure.** H. J. Heine. (*Amer. Foundryman*, 1954, **25,** Jan., 58–61). The problems of machining grey and white cast iron are briefly discussed and it is pointed out that microstructure is much more important than Brinell hardness. Examples are given of microstructures which render cast iron difficult to machine.—B. C. W

**Study on the High Speed Steel.** H. Hotta. (*Tetsu to Hagane*, 1950, **36,** Aug., 357–362; Nov., 556–562). [In Japanese]. Results are given for rapid determinations of elements by spark testing. The hardness, abrasion, and cutting efficiency of 18/4/1 high-speed steel was also examined. Further tests showed that repeated short periods of tempering were better than a long continuous tempering period for high-speed steels. (27 references).—K. E. J.

**A.S.A. Will Simplify Surface Roughness Measurements.** F. W. Witzke. (*Iron Age*, 1953, **172,** Dec. 3, 180–182). Use of arithmetic average microinch readings instead of root-mean-square values are recommended in a proposed revision of American Standard A.S.A. B.46, 1953. A stylus with a tip radius of 500 microinches $\pm 30\%$ and a force not greater than $2\frac{1}{2}$ grains are also to be specified. More consistent and reliable measurements are expected.—A. M. F.

**The Replica Technique Applied to the Measurement of Surface Finish.** N. J. C. Peres. (*Australian Machinery*, 1953, **6,** Dec., 4–10). Existing techniques for the application of surface finish replicas are reviewed, and two techniques developed at the National Standards Laboratory, are described. Both make use of 'solvent-type' replicas, with 4 mm. thick cellulose acetate or Perspex backing pieces. (15 references).

**Intricate Procedures Solve Tough Hard-Facing Problems.** J. Wischhusen. (*Iron Age*, 1953, **172,** Dec. 10, 164–167). Problems involved in hardfacing require for solution combinations of knowledge, skill, experience, and ingenuity. Examples given include the flight edge of an extrusion screw and the cage wall in a steam valve. A heavy machining cut is recommended for removing surplus material followed by grinding with a medium-grit medium-hardness wheel.

**Consett Iron Company Limited: Engineering Workshops.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 93). At the Consett Iron Co. Ltd., all the heavy engineering maintenance is carried out at the central engineering shops. A very brief description of the workshops is given.—G. F.

## CLEANING AND PICKLING

**The Mechanical Descaling and Densening of Surfaces by Shot Blasting.** K. Mathesius. (*Stahl u. Eisen*, 1954, **74,** Mar. 11, 353–355). Recent English and American papers on this subject are reviewed. (14 references).—R. A. R.

**Wet Blasting with Fine Particles.** W. I. Gladfelter, E. E. Hawkinson, A. P. Neumann, and V. W. Nichols. (*S.A.E. J.*, 1953, **61,** Oct., 63–68). This is a condensed article based on three papers presented at the Sept. 1952 meeting of the Shot Peening Division of the S.A.E. Iron and Steel Technical Committee. Blasting with fine particles of Novaculite (99·5% $SiO_2$), in sizes ranging down to 2·5$\mu$, suspended in a liquid carrier produces better finish, tool performance, lubrication, plate adherence, and other improvements in many processing techniques. Details are given of the technical aspects of wet blasting, including the effects of cutting angle, gun distance, and percentage of abrasive, on weight of metal removed.—P. M. C.

**Use of Magnetic Amplifiers in Control Circuits.** R. T. Lucas. (*Iron Steel Eng.*, 1954, **31,** Jan., 74–75). After discussing briefly the advantages of magnetic amplifiers in control circuits, the author describes their first application to control the height of the catenary in the pickling tanks installed in the 66-in. pickling line at the Weirton Steel Co.

**Pickling Equipment for Hand Galvanizing.** H. Rückemesser. (*Draht, English ed.*, 1953, June, 50–52). Designs of pickling frames and baskets for the treatment of small parts are illustrated and described.—J. G. W.

## PROTECTIVE COATINGS

**Electrodeposition of Metal Alloys.** U. Trägårdh. (*Tekn. Tidskr.*, 1954, **84,** Feb. 9, 99–103). [In Swedish]. A discussion of the mechanism of electrodeposition and the structure of the precipitated metal coating is followed by details of alloys now being used on an increasing scale commercially. These include tungsten, molybdenum, and tin mixed with copper, zinc, lead, cadmium, nickel, and antimony. Suitable electrolytes, bath temperatures, current densities, and anode compositions are given.—G. G. K.

**The Production of Plated Steel Strip and Its Properties.** B. Bukovský. (*Hutník*, (Prague), 1953, **3,** (11), 242–245). [In Czech]. The diffusion, rolling, and combined diffusion-rolling methods of plating mild steel strip with an alloy steel surface are described with special reference to Czechoslovakian practice.—P. F.

**Electrodeposition Research.** (*National Bureau of Standards Circular* 529, May 22, 1953). This 129-page book reports the proceedings of the National Bureau of Standards Symposium on Electrodeposition Research on Dec. 4–6, 1951. The papers of principal interest were :

**Research on Electrodeposition in Great Britain.** G. E. Gardam. (1–13).

**Electroplating Research in France.** J. Salauze. (15–22).

**Electroplating Research in Germany, Belgium, and Holland.** (23–26).

**Electrodeposition Research at the National Bureau of Standards.** W. Blum. (27–28).

**Electrodeposition Research at Battelle Memorial Institute.** C. L. Faust. (29).

**Electrodeposition Research at the Bureau of Mines.** O. C. Ralston. (37–40).

**Electrodeposition Research in Progress at Armour Research Foundation.** W. H. Colner. (41–46).

**Electrodeposition Research of Westinghouse Electric Corporation.** G. W. Jernstedt. (47–52).

**Research at Enthone, Inc. on Metal Finishing.** W. R. Meyer. (65–68).

**The Mechanism of Hydrogen Entry into Metals.** L. D. McGraw. (31–33). The mechanism proposed is that atomic hydrogen is deposited on the surface of the basis metal and simultaneously disappears into the metal by diffusion alloying—when hydrogen does not alloy with a given metal there is no entry.

**Brass Plating.** K. G. Compton and R. A. Ehrhardt. (53–55).

**Electroplating in the Sleeve-Bearing Industry.** R. A. Schaefer. (57–63).

**Determination of Impurities in Electroplating Baths.** E. J. Serfass. (73–79).

**Effects of Impurities in Plating Solutions.** D. T. Ewing. J. K. Werner, and A. Brouwer. (81–89).

**Porosity in Perspective.** N. Thon. (91–94). It is pointed out, among other things, that evidence is accumulating to show that single-crystal deposits of nickel are low in occluded hydrogen and are more resistant to the development of porosity than any polycrystalline foils of the same thickness.

**Correlation of Gas Permeability of Electrodeposit with Their Weathering Behavior.** F. Ogburn and A. Benderly. (95–99).

**Properties of Electrodeposited Nickel.** A. Brenner. (101–112).

**Disposal of Cyanide Wastes from Plating Operations.** B. F. Dodge, C. A. Walker, and W. Zabban. (113–120). The authors summarize reports on experimental investigations of methods of disposing of cyanide wastes.

**Current and Metal Distribution in Electrodeposition.** J. Kronsbein. (121–124).

**A New Degreasing Evaluation Test: The Atomizer Test.** H. B. Linford. (125–129). *See J. Iron Steel Inst.*, 1952, **171,** May, 109.

**Electroplating Productivity.** A. Whittaker. (*Metal Ind.*, 1954, **84,** Jan. 15, 49–51). The desirability of increasing efficiency and productivity in the electroplating industry is discussed. Means to this end are considered under the headings : Quality control of plant and solutions, inspection of plated products, plant layout, automatic control, and introduction of newly developed solutions.—P. M. C.

**Statistical Quality Control of Plating Operations.** J. Forster-Cooper. (*Product Finishing*, 1954, **7,** Jan., 48–56).

**Acceptance Sampling of Electroplated Articles.** J. M. Cameron and F. Ogburn. (*Plating*, 1954, **41,** Jan., 43–46).

**Bright Dipping.** R. G. Stewart. (*Trans. Australian Inst. Metals*, 1952, **5,** 113–115). The author briefly reviews the application of bright dipping to copper and copper-base alloys, and to zinc and cadmium plating. The various suitable bath compositions, temperatures, and precautions to be observed are given.—L. E. W.

**Some Aspects of Anodising.** K. H. Belcher. (*Trans. Australian Inst. Metals*, 1952, **5,** 117–122). The author discusses the principles of anodizing and includes tables comparing and classifying the main processes. The mechanism of anodic oxidation, and the composition and structure of anodic coatings are dealt with. (27 references).—L. E. W.

**On the Method of Colouring of Steel. (I).** H. Sawamura and M. Umebara. (*Tetsu to Hagane*, 1950, **36,** Dec., 598–604). [In Japanese]. Conditions were investigated under which colours ranging from yellow to blue were obtained on quenching high carbon steel after treatment in oxidizing atmospheres.

**Electroplating and Soldering as Allied Processes.** A. Whittaker. (*Mech. World*, 1954, **134,** Jan., 26–28). The production of certain components is facilitated by using the processes of electroplating and soldering in combination. Methods are outlined which ensure maximum efficiency when both processes are included in a production layout. Details are given of the factors determining the order in which the two operations should be carried out.—D. H.

**Heats of Adsorption of Ammonia and Hydrogen on Metal Films.** M. Wahba and C. Kemball. (*Trans. Faraday Soc.*, 1953, **49,** Nov., 1351–1360). The heats of adsorption of ammonia and hydrogen at 21° C. on evaporated metallic films of nickel, iron, and tungsten have been measured calorimetrically and the results are given and discussed.—B. G. B.

**Industrial Hard-Chromium Plating.** W. Schmidt and W. E. Hogan. (*Mech. Eng.*, 1954, **76,** Mar., 248–254). The authors give in condensed form some of the data, information, and economics of hard chromium plating compiled specially for engineers and manufacturers. Illustrations are given of its application to machine tools.—D. H.

**New Plating Process Deposits Nickel Brighter, Faster.** C. G. Rising. (*Iron Age*, 1953, **172,** Dec. 24, 78–81). A new solution called Nickel-Lume is claimed to give reduced costs, increased output, and brighter deposits. The bath has good levelling properties, requiring no buffing or polishing before plating. Good ductility and low internal stress of the deposit eliminates cracking and crazing. Temperature and power requirements of the bath are low.—A. M. F.

**Blister and Non-Metallic Inclusion in Steel Sheet.** T. Mishima, Y. Kajikawa, and E. Asano. (*Annual Report Engineering Res. Inst., Tokyo University*, 1953, Dec., No. 12, 42–47). [In Japanese]. The authors discuss experiments to determine

the cause of blistering in galvanized steel sheet. It is concluded that blisters are due to laminations in steel resulting from segregation of non-metallic inclusions which arise during deoxidation and ingot casting. The blister formation is also affected by the acid concentration, temperature, and immersion time during pickling.—L. E. W.

**A Suggested Method of Evaluating the Porosity of Coatings on Ferrous Metals.** T. W. Farrer. (*Chem. Indust.*, 1954, Jan. 16, 77–78). Aqueous suspensions of elemental sulphur attack iron and steel rapidly. As the reaction is specific to ferrous metals it may be used to detect pores in coatings on them. The induction period before rapid attack begins may be reduced from several hours by soluble sulphides or chlorides.

**The Continuous Galvanizing of Steel Strip by the Sendzimir Process.** A. Ollivet. (*Rev. Mét.*, 1954, **51,** Jan., 17–27). The plant necessary for galvanizing strip by the Sendzimir process is described and engineering, electrical control, and operating problems are considered. A special pre-galvanizing heat-treatment in a controlled atmosphere is recommended to clean the steel surface, make the strip more ductile, and ensure that it enters the galvanizing bath at a temperature above the melting point of zinc thereby eliminating brittle intermetallic compounds of iron and zinc.—A. G.

**The Tube Galvanizing Shop of the Société Lorraine-Escaut.** J. Fleischmann. (*Rev. Mét.*, 1954, **51,** Jan., 28–35). The plant in a highly mechanized tube galvanizing shop is briefly described and the successive operations of cleaning, rinsing, fluxing, dipping, removal, wiping, cooling, and inspection are dealt with in detail. The consumption of zinc and fuel, output, working conditions, and productivity are also discussed.

**Galvanizing Embrittlement of Blackheart Malleable Iron.** G. N. J. Gilbert. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1953, **5,** Dec., 124–131). Embrittlement occurs due to the heat-treatment at approximately 450° C. followed by the customary water quench received during the galvanizing process. The susceptibility of an iron to embrittlement increases with increasing phosphorus and/or silicon, but the effect of phosphorus is much more pronounced than silicon. Galvanizing embrittlement in susceptible irons can be avoided by quenching in water from 650° C. before galvanizing.—B. G. B.

**Metallography of Tin, Tin Alloys, and Tin Coatings on Steel.** J. Teindl. (*Hutnické Listy*, 1954, **9,** (2), 95–98). [In Czech]. Metallographic methods of examining tin and tin coatings on steel are discussed, with special reference to recent developments in microscopy. Modern methods of mounting, polishing, and etching specimens are surveyed. Improvements in these methods should render them suitable for studying : (1) The nature and brittleness of the intermetallic layer in tinned steel ; (2) methods of sealing tins ; and (3) researches on tin alloys.—P. F.

**New Corrosion Resistant Coating Protects Cast Iron Coolers.** J. J. Obrzut. (*Iron Age*, 1953, **172.** Dec. 24, 76–77). A new product ' Kolmetal ' consists of a mixture of 85% by volume of finely pulverized aluminium in a special plastic vehicle. The resultant plastic bonded coating maintains its heat-transfer efficiency while resisting corrosion. Tests on acid cooling coils have shown a considerable increase in operating life.—A. M. F.

**Abrasion Resistant Coatings Sprayed on Metal Surfaces.** W. G. Patton. (*Iron Age*, 1953, **172,** Dec. 3, 172–173). A brief description is given of the Colmonoy Sprayweld process. A nickel-based alloy containing both chromium and boron is first sprayed on to a roughened surface. To provide a fusion-bonded non-porous coating the surface is then heated to 1900° F. when the alloy becomes plastic and bonds to the base metal.—A. M. F.

**Abrasion Resistance of Some Dry-Process Enamels.** W. C. Spangenberg. (*J. Amer. Ceram. Soc.*, 1954, **37,** Feb., 48–51). Experiments are reported on the effect of several variables on abrasion resistance of some enamels on cast iron. A weight loss method of measurement was used which differentiates between surface and subsurface abrasion. Data obtained on eight commercial enamels showed the general superiority of acid-resistant enamels compared with non-acid-resisting compositions.—D. L. C. P.

**Differential Thermal Analysis of Titania-Opacified Enamels.** F. D. Olympia. (*Amer. Ceram. Soc. Bull.*, 1953, **32,** Dec., 412–414). Differential thermal analyses were carried out on five enamels with 9·3 to 23·4% $TiO_2$ to study nucleation, crystallite growth, and enamelling techniques, as affecting the physical properties of the enamel.—D. L. C. P.

**Relation Between Roughness of Interface and Adherence of Porcelain Enamel to Steel.** J. C. Richmond, D. G. Moore, H. B. Kirkpatrick, and W. N. Harrison. (*J. Amer. Ceram. Soc.*, 1953, **36,** Dec., 410–416). An investigation and results are described. A positive correlation was found between the adherence of porcelain enamel ground coat to steel and the roughness of the interface. Roughness is necessary but is not the only condition for the development of a good bond. Most of the roughness that is associated with good adherence apparently develops during the firing process.—D. L. C. P.

**Galvanic Corrosion Theory for Adherence of Porcelain Enamel Ground Coats to Steel.** D. G. Moore, J. W. Pitts, J. C. Richmond, and W. N. Harrison. (*J. Amer. Ceram. Soc.*, 1954, **37,** Jan. 1–6). The galvanic corrosion theory is explained and supporting evidence reviewed. Experiments were performed demonstrating that galvanic corrosion of the metal base could occur during firing of enamel coats. The theory requires that the adherence is obtained by subsequent mechanical anchoring, but several points are noted which could not be explained by the theory, indicating that there may be other factors involved.—D. L. C. P.

**Industrial Furnaces: Enamelling—Galvanizing.** (*Iron Age*, 1954, **173,** Feb. 25, F26–F27). Installations for galvanizing water tanks and enamelling kitchen sinks are briefly described.—R. A. R.

**East Anglian Founders Install Enamelling Plant.** (*Found. Trade J.*, 1954, **96,** Feb. 4, 135–138). A description is given of the recently completed vitreous enamelling shop at Suffolk Iron Foundry (1920) Ltd., Stowmarket.—B. C. W.

**Porcelain Enamels and Ceramic Coatings, Prime Inhibitors of Metal Corrosion.** D. G. Bennett. (*Corrosion*, 1954, **10,** Jan., 13–20). The present and possible uses of ceramics as protective coatings are reviewed. Test methods are described. The coatings have high resistance to corrosion, heat, abrasion, and vibration.—J. F. S.

**Developments in Vitreous Enamelling on Steel in the United States.** E. M. Hommel. (*Found. Trade J.*, 1954, **96,** Jan. 7, 19–24). Details are given of recent developments in vitreous enamelling including the direct application of a finish coat to steel which has not received a ground coat. In the Eckel-Romine process the article is pickled in acid, given a nickel dip and then decarburized at about 600° C. ; after cooling, the finish coat is applied directly to the base metal. The Ferro-Republic process includes a deep etch with nitric acid and a nickel dip in which nickel is deposited by chemical reduction rather than by galvanic displacement ; both these steps require close control. In a process used by the Westinghouse Electric Corp. special titania-opacified enamels are applied directly to articles made from titanium steel. Other recent developments in enamelling include stable pastel coloured titania-opacified enamels, luminescent enamels, improved methods of spraying and a new adherence meter.

**Reaction Primers for Painting Metals.** B. Elfisch. (*Werkstoffe u. Korrosion*, 1954, **5,** Feb., 54–56). This is a short general review, with references to American, French, and Swiss work, of recent developments in the technology and uses of reaction primers to prepare the surface of steel and other metals for painting, *e.g.*, ' wash primers ' of the phosphoric acid, polyvinyl butyral, zinc chromate type.—J. C. H.

## POWDER METALLURGY

**The Sintering Process.** P. R. Kalischer. (*Precision Met. Mold.*, 1953, **11,** Oct., 58–59 ; Nov., 44–46). In Part I the author deals briefly with the theoretical aspects of sintering in powder-metallurgy processes. The influence of surface and volume diffusion on sintering and the factors affecting solid solubility are dealt with. Sintering furnaces are briefly discussed in Part II.—D. H.

**Preparation and Properties of Electrolytic Iron Powder.** I. Ljungberg. (*Stahl u. Eisen*, 1954, **74,** Feb. 25, 279–285). The theoretical and technical bases of various methods for preparing electrolytic iron powder are discussed. In the HVA process, developed by the Husqvarna Vapenfabriks AB., Sweden, the electrolyte, bath temperature, and operating conditions are chosen so that a coherent, yet readily grindable, cathode deposit is formed. This deposit is removed from the cathodes, washed, dried, and ground in a ball mill. It is then reduced and re-ground. The powder is of very high purity and its physical properties can be modified over a wide range by choosing conditions of electrolysis, grinding, and reduction.

It has been found convenient to produce two grades of powder. The HVA Standard Powder is suitable for producing sintered components of high density by the double pressing method and the HVA Sponge Powder is for use in making sinters with high elongation at fracture.—J. P.

**Piston Rings of Iron Powder.** A. Hermanns. (*Precision Met. Mold.*, 1954, **12,** Feb., 35–37, 78–81). German experience with sintered iron piston rings is described. The rings made by the pressing and sintering of powders of iron, alloying elements, and graphite have many advantages over cast steel and cast iron rings.—D. H.

**Recent Developments in the Field of High Melting Point and Rare Metals.** F. Benesovsky. (*Stahl u. Eisen*, 1954, **74,** Feb. 11, 210–215). The methods for the production of pure titanium, zirconium, hafnium, vanadium, niobium, tantalum, chromium, molybdenum, and tungsten in ingot form are reviewed. The vacuum arc furnace is employed for the melting of the sponge or powder in which form the metal is first isolated.—J. P.

**Technical Sintered Materials from the Iron-Copper System.** G. Zapf. (*Stahl u. Eisen*, 1954, **74,** Mar. 11, 338–347). The production and mechanical properties of sintered compacts made by various methods are discussed. The methods comprise impregnating sintered iron with copper or copper alloys to a copper content of 15–25% ; pressing and sintering a mixture of iron and copper powders containing 5–10% copper ; and repeated pressing and sintering of an iron powder containing 0·5–5% copper. The application of these sintered materials to a wide range of components is described and illustrated.

**Sintered Self-Lubricating Bushes.** J. Valenta. (*Tech. e Industr.*, 1953, **31,** Dec., 1444–1445). [In Spanish]. The author discusses pure iron, iron and lead, and iron and metallic oxides as three separate types of material for bearings made by powder metallurgy. The operation and advantages of self-lubricating bearings are explained.—R. S.

**Self-Lubricating Iron Bearing.** W. Cegielski. (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6,** (6), 338–358). [In Polish]. Developments in the manufacture and application of self-lubricating bearings and materials used for their production are surveyed. The influence of forming pressure, sintering temperature, and particle size on the mechanical properties of sintered iron bushes were studied.—V. G.

**Industrial Furnaces: Sintering—Brazing.** (*Iron Age*, 1954, **173,** Feb. 25, F19–F25). Furnaces for sintering metal powders and the bright heat-treatment of stainless steel and other metal parts are described.—R. A. R.

**Metal Powders Ease Production Headaches.** A. G. Gray. (*Steel*, 1954, **134,** Jan. 25, 88–91). Examples of iron and non-ferrous sintered metal powder parts are given, and advantages and limitations of the process set out.—D. L. C. P.

## PROPERTIES AND TESTS

**Examination of Methods for Determining Primary Permanent Elongation.** G. Malmberg. (*Jernkontorets Ann.*, 1954, **138,** (1), 39–52). [In Swedish]. Four methods of measuring permanent elongation, developing between the beginning of the yield range and maximum stress, are critically reviewed. Details are given of comparative tests using two of the methods, 550 steel samples being tested. Results are presented of direct measurements and of calculated values.

**The Nature of Failure During the Plastic Deformation of Metals.** S. I. Gubkin and L. A. Rapoport. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (4), 685–688). [In Russian]. The nature of the failure of metals during plastic deformation is discussed. The characteristic feature of plastic deformation is that it is restricted to the area of maximum tangential stresses where, according to the law of additional stresses, the tensile stresses appear. In the neighbourhood of these areas structural changes (independent of the mode of deformation) and, under certain conditions, phase transformations take place as a result of which ' local layers ' are formed. In these layers microcracks are formed which may lead to the failure of the metal.—V. G.

**Behaviour of Materials at Stresses Higher than the Elastic Limit.** Serafin San Juan Rubio. (*Anales de Mecanica y Electricidad*, 1953, **30,** Nov.-Dec., 310–316). [In Spanish]. The author discusses quantitatively the evaluation of stresses above the elastic limit during deformation.—R. S.

**The Effect of Static and Dynamic Loading and Temperature on the Yield Stress of Iron and Mild Steel in Compression.** J. M. Krafft, A. M. Sullivan, and C. F. Tipper. (*Proc. Roy. Soc.*, 1953, **A221,** Jan. 7, 114–127). Results are given for cylindrical test samples in the range 100° to −195° C. The stress necessary to initiate yield rises steeply with fall in temperature; being accompanied by a change in the mechanism of deformation to Neumann lamellæ at a critical temperature; this is higher under dynamic loading, but there appears also to be a critical stress for lamellæ formation.—K. E. J.

**Stress-Strain Records at High Straining Rates.** F. G. Tatnall and G. Ellis. (*Non-Destructive Test.*, 1953, **11,** Nov.-Dec., 32–34). The recording of load/deformation curves of structural parts subjected to short duration impact forces is discussed in general terms. The use of bonded electrical resistance strain gauges and the necessary equipment is described and illustrated.—P. M. C.

**Development of a Method for Determining the Brittle Fracture Tendency of Low-Carbon Unalloyed Steel.** (*Lastechn.*, 1953, **19,** Dec., 247–264). [In Dutch]. Results are given of dynamic and static notched-bar tests on several structural steels. A method evolved by van der Veen of the Dutch State Steelworks at Ijmuiden proved eminently satisfactory. It consists of a hydraulic apparatus operating at about 20 mm./min. on notched specimens at different temperatures. It is pointed out that in spite of its inherent defects the recognized notched-bar impact test cannot be dropped at present because of its wide international use and it is suggested that the Charpy test be adopted internationally.

**Dislocations, Plastic Flow and Creep.** N. F. Mott. (*Proc. Roy. Soc.*, 1953, **A220,** Oct. 22, 1–14). An outline is given of the evidence of normal existence, formation, and movement of dislocations ; the formation of networks of dislocations and the stability of piled groups are discussed. The Frank-Read theory of the origin of slip lines is surveyed ; the explanation of coarse slip may depend on whether moving dislocations can approach sonic speed. A theory of ductile fracture is advanced, and recovery and creep are discussed.—(72 references).—K. E. J.

**Ruptures in Marine Boiler Tubes. Studies Undertaken by Instituto Nacional de Tecnologia to Investigate Their Causes.** A. H. da Silveira Feijó, S. Maurell Lobo Radino, M. Regina Veloso da Silveira, E. Goulart de Andrade, and H. Lodewijk Radino. (*Bol. Assoc. Brasil Met.*, 1953, **9,** July, 366–381). [In Portuguese]. Tests showed that the overheating of the tubes was the primary cause of the ruptures. The following were the main causes of the overheating : (1) Abnormally low water level or irregular distribution of the hot gases in the furnace ; (2) presence of extraneous bodies in the water tubes ; (3) local incrustations ; (4) sudden variations in the rate of evaporation ; and (5) local contact with the flame.—R. S.

**Report on the Failure of a Water Tube in a Steam Generator.** M. Danti. (*Calore*, 1954, **25,** Jan., 11–17). [In Italian]. The author describes the failure which occurred in a water tube of a steam generator. The failure occurred at a water pressure of 750 kg./sq. cm. Tests carried out on the tube showed that it was not to specification.—M. D. J. B.

**Brittle Failure of Non-ship Steel Plate Structures.** M. E. Shank. (*Mech. Eng.*, 1954, **76,** Jan., 23–28). The author examines and correlates data relating to brittle failure in structures other than ships. Failures in welded and riveted pressure vessels, tanks, bridges, and gas tranmisssion lines are discussed.—D. H.

**Relation of Fatigue to Automobile Rear Axle Failures.** B. Grindrod. (*J. Inst. Auto. Aeronaut. Eng.*, 1953, **13,** Nov., 560–566). The author first discusses the theory of fatigue from the stressed axle point of view and then deals with some methods adopted by designers to combat fatigue; such processes as surface-hardening, and the effects of surface finish and steel alloying are briefly considered.—L. E. W.

**The Growth of Fatigue Cracks.** A. K. Head. (*Phil. Mag.*, 1953, **44,** Sept., 925–938). The qualitative features of the growth of a fatigue crack are discussed. A model showing these features is proposed ; it enables quantitative predictions, in agreement with experimental measurement, to be made. It is concluded that cracks may be formed at an early stage in fatigue and that the growth of a crack may occupy a large part of the measured fatigue life.—K. E. J.

**Biaxial Fatigue Properties of Pressure Vessel Steels.** C. E. Bowman and T. J. Dolan. (*Welding J.*, 1953, **32,** Nov., 529s–537s). Studies were made to determine the resistance of a carbon steel and a low-alloy steel plate (Mn 1·44%, Mo 0·43%) to fracture under repeated loading and to evaluate

the relative reduction in strength resulting from stress raisers imposed by design, fabrication, or handling. The fatigue life of the alloy steel was appreciably greater than that of the carbon steel when subjected to cyclic strains up to those that exceeded the yield-point strain of the latter by as much as 75%, but at higher strains this trend was reversed. A submerged-arc weld, ground flush with the parent metal, did not reduce the fatigue resistance of either type of steel.—U. E.

**Dynamic Properties of Nodular Cast Iron. Part 2—Size Effect.** H. Majors, jun. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76,** Feb., 205–216). Rotating-beam endurance tests at room temperature have been carried out on a magnesium-treated cast iron of composition C 3·28%, Si 2·39%, S 0·013%, P 0·03%, Mn 0·30%, Mg 0·10%, and Cu 1·15%, tested in 0·86 in. min. dia. notch sections and 1·25 in. min. dia. unnotched sections. These tests were carried out to compare fatigue data obtained from geometrically similar specimens having minimum diameters of 0·19 and 0·30 in. respectively. There was no significant difference in the endurance limits of sections of annealed or as-cast large castings as measured on specimens ranging from 1·25 in. to 0·30 in. in dia.—D. H.

**Practical Aspects of Hardness Testing of Hardened Steel Strip.** G. Molinder. (*Jernkontorets Ann.*, 1954, **138,** (2), 81–96). [In Swedish]. A review of the efficiency of known methods of hardness testing as applied to the testing of cold-rolled strip criticizes methods employing the surface of the strip since inaccuracies may well result due to decarburization. The Vickers method, in which the strip cross-section is tested using a pyramid or Knoop indenter, is recommended and the correlation established between Vickers hardness and ultimate tensile strength. Disadvantages of the Rockwell test are also pointed out.—G. G. K.

**A Note on the Temperature Dependence of Hardness.** E. D. Kunst. (*Metalen*, 1954, **9,** Jan. 31, 23–24). [In Dutch]. An explanation is offered concerning the sudden break in logarithmic Brinell-hardness/temperature curves commencing about midway in the absolute temperature scale. Curves indicate that the ball comes quickly to rest at temperatures below the knee in the curve while it comes to rest more slowly at temperatures above.—F. R. H.

**Characteristic Features and Limitations of the Concept of Vickers Microhardness.** H. Bückle. (*Rev. Mét.*, 1954, **51,** Jan., 1–12). The causes of error in microhardness testing have been comprehensively studied. Three ranges of Vickers hardness are distinguishable: (*a*) Microhardness, with 1–200 g. loads ; (*b*) low hardness loads of 200 g. to 10 kg. ; and (*c*) ordinary macrohardness, loads above 10 kg. The justification for these divisions is discussed by considering the effects of such factors as applied load, optical system, rate of application of load, and surface smoothness.—A. G.

**A Method of Verifying Rockwell Hardness Machine Depth Indicators.** R. J. Ellis. (*J. Sci. Instruments*, 1954, **31,** Mar., 109). Dial gauge readings are compared with known vertical displacements by the use of six slip gauges differing in thickness by increments of 40 $\mu$ ; the actual sequence of movements in making a hardness determination is simulated. The datum position is established with a horizontal vibrating reed.

**On the Behaviour of Hardness-Curve of Quenched Steel (I).** T. Mishima and T. Mitsuhashi. (*Tetsu to Hagane*, 1950, **36,** June, 268–278). [In Japanese]. Results are given of experiments on low, medium, and high carbon steels. There are two types of hardness curve, flat and stepped ; the latter appears in steels containing hard soluble carbides (Cr–V, Cr–Mo and Si–Mn–Cr steels). Cr–V steel exhibits age-hardening at room temperature. The quantity of residual austenite in Si–Mn–Cr steel permits a reasonable hardening by tempering. (25 references).—K. E. J.

**Effect of Chemical Composition and Quenching Temperature on the Increase of Tensile Strength of Water-Hardened Spiral Spring Wire Made of Rimming Basic-Bessemer Steels.** R. Grimm and A. Krüger. (*Stahl u. Eisen*, 1954, **74,** Mar. 11, 331–335). Tensile tests carried out on eight steels (0·06–0·09% C, 0·27–0·36% Mn, 0·05–0·08% P, 0·03–0·04% S, 0·010–0·015% N), as normalized, water-quenched from 700° C., and stored for up to 29 days, have shown that there is a relationship between chemical composition, quenching temperature, storage time, and increase of tensile strength. The initial strength also affects the strength after 29 days' storage, the increase being greater with the softer steels. The greatest tensile strength increase was exhibited by the steel with the lowest phosphorus content. In order to obtain high final strengths, the initial strength must be high and the phosphorus content held low. The quenching temperature also has an effect on tensile strength ; a value of just below the $Ac_1$ point should be aimed at for mild steel for water-quenched spiral spring wire.—J. P.

**Accelerated Strain Ageing of Mild Steel.** B. B. Hundy. (*J. Iron Steel Inst.*, 1954, **178,** Sept., 34–38). [This issue.]

**Boiler Plate Embrittlement.** S. D. Scorer. (*Mech. World*, 1953, **133,** Dec., 558–559). The author discusses briefly boiler plate embrittlement and caustic cracking. He suggests that it is caused by the high stresses inherent in the design, construction, and operation of riveted seams, rather than by chemical attack.—W. H.

**On Brake Burns of Wheel Tyres.** S. Owaku, K. Iishima, and N. Kashiwagi. (*Tetsu to Hagane*, 1950, **36,** Aug., 345–349). [In Japanese]. The cracking of railway tyre flanges is attributed to the formation of a hardened and tempered zone (resulting from heating by the brakes) accompanied by temper cracks ; these develop into flange cracks through repeated stress during rolling.—K. E. J.

**Present-Day Magnetic Materials.** H. Fahlenbach. (*Inst. Hierro Acero*, 1953, **6,** Oct.-Dec., 309–320). [In Spanish]. The nature of ferromagnetic materials is discussed and the quality of materials used in the manufacture of permanent magnets is reviewed. Krupp's Widia permanent magnets are described.—R. S.

**Study on Permanent Magnet Alloy (IV).** T. Mishima and N. Makino. (*Tetsu to Hagane*, 1950, **36,** May, 206–211). [In Japanese]. In the Fe–Mn alloy, hardening results from the dispersion of austenite in martensite. In Köster alloy, it results from precipitation. In Cunife alloy, it is obtained after coagulation of two precipitated phases. In Fe–Al–C alloy it results from transformation followed by precipitation. In M. K. steel, hardening accompanies the initial phase of precipitation.—K. E. J.

**Some Magnetostriction Relations in Materials Possessing Preferred Domain Orientations.** G. T. Rado. (*J. Appl. Phys.*, 1954, **25,** Jan., 102–106). Simple relations between certain magnetostrictive strains derived for polycrystalline ferromagnetic materials possessing a preferred axis in the distribution of domain orientations show good agreement with experimental results.—J. O. L.

**A Method of Measuring Magnetostriction.** A. W. Cochardt. (*J. Appl. Phys.*, 1954, **25,** Jan., 91–95). The different relationship between shear stress and strain in torsion for magnetized and unmagnetized wires of ferromagnetic materials is explained and magnetostriction measured therefrom to an accuracy of $4 \times 10^{-7}$. The method can be used at high temperature, but saturation values cannot be determined for alloy with large crystal anisotropic energy.—J. O. L.

**Ferromagnetism and the Curie Point.** B. M. Aldrich. (*Oklahoma Engineering Experiment Station Publ. No.* 83, 1952, **19,** Mar., 2–42). The author first covers briefly the history of magnetism and the magnetic classification of materials. Some observed magnetic effects and the theories of magnetism are discussed. He then deals in some detail with the Curie point, and the heat-treatment of carbon steels in a magnetic field on the basis of results from 200 tests on various steels. (11 references).—L. E. W.

**A General Approach to Hysteresis. Part 2. Development of the Domain Theory.** D. H. Everett and F. W. Smith. (*Trans. Faraday Soc.*, 1954, **50,** Feb., 187–197). The independent domain theory of hysteresis outlined in a previous paper is developed to take account of a more general distribution of domain properties than that employed previously.

**Heat-Treatments and Physical Properties of Silicon Steels.** M. P. de Andres Sanz. (*Inst. Hierro Acero*, 1953, **6,** Oct.-Dec., 393–400). [In Spanish]. In view of the influence exerted by annealing and the manufacturing process on the watt losses of silicon steel sheets, a study is made of 'over-annealing' at 1200–1250° C. and its effects are compared with normal heat-treatment at 900° to 950° C.—R. S.

**Influence of Magnetostriction and of the Piezo Electric Effect on the Development of Ultrasonics.** J. Ors Martinez. (*Inst. Hierro Acero*, 1953, **6,** Oct.-Dec., 381–392). [In Spanish]. The author reviews early developments in physics which led to our present knowledge of ultrasonics and their use in some industrial fields.—R. S.

**Ultrasonic Inspection Using Automatic Recording and Frequency Modulated Flaw Detector.** D. C. Erdman. (*Non-Destructive Test.*, 1953, **11,** Nov.-Dec., 27–31). An attempt is made to show the requirements for a complete description of internal flaws. The design of a hypothetical ideal flaw detecting machine and the problems faced are discussed. The presentation of data from side and top scans, showing both depth and area of flaws, is described, and instruments which have been developed to do such double scanning are described and illustrated.—P. M. C.

**The Ultrasonic Permeability of Steel and its Significance in Pulse-Echo Test Results.** A. Michalski. (*Stahl u. Eisen*, 1954, **74,** Jan. 1, 26–33). The detection of internal defects in large steel components and determination of their size necessitates an adequate and uniform permeability to ultrasonic vibrations. Some types of metallic structures which reduce permeability are described. A method is proposed for measuring permeability and the use of the results in assessing pulse-echo records is discussed.—J. P.

**Non-Destructive Flaw Detection.** R. Schnurmann. (*Eng. Insp.*, 1953, **17,** Summer, 67–75, 58). The magnetic particle method of crack detection is described in some detail, and the use of fluorescent inks is discussed, with particular reference to the examination of non-magnetizable materials. Some general observations are presented on other non-destructive testing methods.—P. M. C.

**A Technique for Gamma Ray Exposure Determination.** C. E. Juran. (*Non-Destructive Test.*, 1953, **11,** Nov.-Dec., 25, 26). The use of graphs showing exposure time *versus* steel thickness for varying source-film distances is discussed. Such charts are applicable to particular radioactive sources and types of film, and can be compiled from accumulated data.

**Effects of Source and Specimen Dimensions on Resolution in Gamma Radiography.** A. J. Stevens. (*Non-Destructive Test.*, 1953, **11,** Nov.-Dec., 13–15). A general quadratic equation is developed which expresses the dispersion to be expected from a gamma source in terms of the geometry of the exposure set-up. The most useful size of source available in the U.S.A. is $\frac{1}{8}$ in. dia. rod of cobalt$_{60}$, the optimum length being $\frac{1}{2}$ in. A curve is given which relates specimen dimensions to source-film distance for a 'standard' source of the above dimensions.—P. M. C.

**Some Experimental Findings and Operating Practices in Betatron Radiography.** N. C. Miller and J. D. Steely. (*Non-Destructive Test.*, 1953, **11,** Nov.-Dec., 35–40). The $3\frac{1}{2}$ year history of a 22 MeV. fixed beam betatron installation is summarized. Maintenance procedures are outlined, and practical methods of beam alignment and focal spot correction are described. Typical applications are discussed and illustrated, such as radiography of thick steel, use of the high subject latitude inherent in the 22 MeV. radiation, direct magnification during radiography, and methods of stereoradiography. Brief descriptions are given of: (1) The use of shaped compensators to produce uniform beam intensity within a prescribed angle; (2) the usefulness of a vacuum-type cassette; (3) a comparison between radiographic and photographic enlargement; and (4) optimum intensifying screen thicknesses under various conditions. Head screen combinations ranging from 0·010 in. to 0·120 in. front and 0 to 0·040 in. back are evaluated.

**Further Applications of Non-Destructive Methods of Testing Welds.** O. Vaupel. (*Schweissen u. Schneiden* 1954, **6,** Mar., 108–109). Improvements in non-destructive methods of testing welds are reported.—U. E.

**Cobalt-60—Inspection Uses are Growing.** D. E. Brewer. (*Iron Age*, 1953, **172,** Dec. 31, 80–82). Some of the applications of radioactive Co$_{60}$ for inspection are given. The most important are for pressure vessels, critical castings, and ship and structural welds. Advantages are a powerful, portable and comparatively inexpensive source for radiography, and the ability to operate in confined spaces inaccessible to X-ray machines.—A. M. F.

**Application of Radio-Active Isotopes to Steel Foundry Radiography.** L. Wilkinson. (*Engineer*, 1954, **197,** Mar. 12, 383–387). In this survey of the use of radioactive isotopes in steel foundry radiography, the author examines the physical principles and practice of the techniques, and shows that the radio-active properties of Co$_{60}$, Ta$_{182}$, and Ir$_{192}$ are mainly complementary and that they enable thicknesses ranging from $\frac{1}{2}$ in. to 5 in. of steel to be examined with adequate contrast and sensitivity.—M. D. J. B.

**What's New in Nondestructive Testing.** S. A. Wenk. (*Steel* 1954, **134,** Jan. 18, 78–81). Recent testing techniques and applications are reviewed, particularly equipment for production-line and portable use.—D. L. C. P.

**Some Industrial Applications of Radio-Isotopes.** C. Croxson. (*Welding Metal Fab.*, 1954, **22,** Jan., 15–20). A review is given of applications involving the use of small expendable amounts of isotopes of short life, and of relatively large sources of radiation requiring careful handling which have a comparatively long life.—U. E.

**Application of Radioisotopes in Engineering Industry.** D. J. Stern. (*J. S. African Inst. Mech. Eng.*, 1953, **3,** Nov., 121–146). The nature and characteristics of radioisotopes and their production in the nuclear reactors are explained. All nuclear concepts are presented graphically. Two main application fields of radioisotopes are described, namely, the use of radioisotopes as sources of energy and the use of the penetrating power of radiation emitted by them. The principle of gamma ray radiography, method of use, and instrumentation are given briefly. Autoradiography and applications of tracer methods and techniques in engineering are dealt with. The problem of radiation hazards and protection is treated from the viewpoint of a practical engineer. Maximum permissible exposures are given.—L. E. W.

**Table of Isotopes.** J. M. Hollander, I. Perlman, and G. T. Seaborg. (*Rev. Modern Phys.*, 1953, **25,** Apr., 469–651). A complete table is given of radioactive and stable isotopes of the elements known at December, 1952, with some additional information and about 1400 references.—J. O. L.

**Thermal Expansion of Simple Solids at Low Temperatures and Grüneisen's Law.** D. Bijl and H. Pullan. (*Phil. Mag.*, 1954, **45,** Mar., 290–294). Experimental results on metals including iron show that Grüneisen's law breaks down at low temperatures ($<0{\cdot}3\theta$), the thermal expansion becoming greater than the predicted value. A possible theoretical explanation is given.—K. E. J.

**Materials for High Temperature Service.** H. C. Cross. (*Indust. Heating*, 1953, **20,** Aug., 1492–1496, 1620; Oct., 1986–1996; Dec., 2416–2420; 1954, **21,** Jan., 154–160). The particular applications and service temperatures for which plastics are suitable are considered in Part I. Aluminium, titanium, chromium, and molybdenum are dealt with in Part II. Combinations of metals and ceramics (the cermets) are reviewed in Part III. The concluding part (IV) deals with ceramic materials and their applications, other than furnace linings.—R. A. R.

**The Heat Treatment of High Temperature Materials.** T. E. Cound. (*Eng. Insp.*, 1953, **17,** Autumn, 101–110). A very brief outline of the main characteristics of metallic creep is given, and the importance of this property in the development of alloys for jet engine rotor blades is discussed. The author classifies these alloys as non-age-hardening, mild age-hardening, strong age-hardening, and precision cast (cobalt base). Compositions, treatments, and 1000-hr. rupture strengths over the temperature range 650–870° C. are given. General data concerning the effect of heat-treatment on creep properties are discussed, and the effect of grain size, and its dependence on heat-treatment temperature is briefly described, and notes on the importance of oxidation resistance are included. (11 references).—P. M. C.

**Tensile Testing at High and Low Temperatures.** K. W. Mitchell. (*Product Eng.*, 1953, **24,** Aug., 197–203). Methods of heating a specimen and measuring extension are described and it is stressed that extensometer sensitivity and the rate of straining must be quoted to give comparable results. For low temperature testing isopentane is recommended, the possible temperature range being from +82° to −256°F. and details of a suitable cooling chamber are given. At low temperatures the provision of a uniform axial stress is important. Graphs showing the variation in tensile properties of iron and various steels at low temperatures are given.

**Influence of Microstructure on the Hot Strength of Steel.** G. Delbart and M. Ravery. (*Metal Treatment and Drop Forg.*, 1953, **20,** Dec., 579–589). Previous work (*see J. Iron Steel Inst.*, 1950, **166,** Dec., 383) on the effect of heat-treatment on the rate of creep of low-carbon Cr–Mo steels at various temperatures has been extended. The previous tests were of short duration and on one cast only, for which reasons the present tests were carried out for 1000 hr. at 450° C. and 575° C. on the same steel and on two others with higher carbon content. The influence of microstructure, which was

varied by a range of heat-treatments, was again examined, and the effect of soaking the specimens at the testing temperatures and also at 700° C. before conducting the tests was studied. (5 references.)—P. M. C.

**On the High Temperature Creep Testing of Heat Resisting Steels.** T. Mishima, F. Nakanishi, T. Akutagawa, J. Miyama, K. Hatta, and T. Okazaki. (*Annual Report Engineering Res. Inst., Tokyo University*, 1953, Dec., No. 12, 16–23). [In Japanese]. In testing the creep strength of heat-resisting steels at high temperatures the authors found it necessary to adopt the following voltage and temperature controls : (1) A reactor-type automatic regulator to compensate voltage fluctuations ; and (2) a Prosser's circuit electronic temperature controller for the furnace. In addition, the effect of fluctuations in room temperature was avoided by observing the creep strain directly with a microscope through a window in the furnace wall.—L. E. W.

**Proposal for Design Data for Pressure Vessel Steels above 350° C.** C. Schaub. (*Jernkontorets Ann.*, 1954, **138,** (2), 53–80). [In Swedish]. Design data proposed for 13 alloyed and unalloyed Swedish steels take into account actual test results and foreign standards. The stress/temperature curves shown are based on the thermal yield limit at lower temperatures and on the creep limit of 0·01%/1000 hr. at higher temperatures. Analysis limits, highest permissible operating temperatures, and heat-treatments are also given.—G. G. K.

**The Properties of Steels for Casting Blades of Kaplan Turbines.** A. Nemes. (*Slévárenství*, 1954, **2,** (1), 2–9). [In Czech]. The development of materials used since 1919 for Kaplan turbine blades is outlined, and the advantages and disadvantages of high-alloy and low-alloy steels as blade material are discussed with reference to corrosion, weldability, strength, heat-treatment, cavitation, and impact strength. An outline of probable developments in the choice of steels is given.—P. F.

**High Purity Chromium Key to Better Alloys.** H. L. Gilbert and H. A. Johansen. (*Iron Age*, 1954, **173,** Jan. 21, 93–96). The properties of high-chromium alloys (60% Cr, 40% Fe), and commercial chromium metal are briefly discussed and it is suggested that marked improvements may be made if they are of high purity. Six methods of making high purity chromium are described, none of which are really satisfactory. From the standpoint of metallic contamination the best available form is electrolytic plate. (15 references).—A. M. F.

**Structural Changes in Metals During Creep.** B. M. Rovinskii and L. M. Rybakova. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1953, (9), 1241–1247). [In Russian]. An analysis is made of the character of the structural changes during creep of Armco iron at 400 and 450° C. and steel EYA-IT at 575–625° C. at various permanent deformations. It was found that qualitatively structural changes during creep are analogous to the structural changes during normal plastic deformation, and the changes equivalent to the same permanent deformation in both processes are less noticeable with increasing temperature.—V. G.

**Behaviour of Carbon and Low-Alloy Steels Between −20° and +650° F.** G. H. Enzian. (*Welding J.*, 1953, **32,** Dec., 605s–618s). The literature on the brittleness induced either by low temperatures or by strain ageing in carbon and low-alloy steels is reviewed. It is shown that certain steels may be susceptible to such effects in temperature ranges which, from the engineering viewpoint, are normally considered neither high nor low.—U. E.

**On the Effect of Vanadium on the Low Tungsten-Chromium Steel for Hot Working.** S. Koshiba. (*Tetsu to Hagane*, 1950, **36,** July, 325–328). [In Japanese]. The results of additions of vanadium in the range 0·3–1·0% showed that the optimum proportion is 0·4–0·7% in a steel containing 0·20–0·25% C, 2·5% Cr, and 5% W.—K. E. J.

**Effect of Nitrogen Addition to Stainless Steel.** T. Mishima and T. Fujita. (*Annual Report Engineering Res. Inst., Tokyo University*, 1953, Dec., No. 12, 111–116). [In Japanese]. Experiments are discussed in which the effect of nitrogen in stainless steel was investigated using metallographic studies in conjunction with hardness and corrosion resistance measurements. A low-nickel austenitic stainless steel can be produced by substituting nitrogen for part of the nickel, and the following composition seems to be the optimum for use in weakly corrosive environments : Cr 20–22, Ni 5·5–6·0, $N_2$ 0·18–0·22, C 0·10%. Higher chromium results in the formation of the α-phase and it is necessary to add more nitrogen which is apt to cause unsoundness. With less chromium martensite tends to appear. With molybdenum present the higher nickel content should be used.—L. E. W.

**Study on the High Mn-Cr Steels Containing Nitrogen.** K. Deguchi. (*Tetsu to Hagane*, 1950, **36,** May, 216–227). [In Japanese]. To obtain high precipitation-hardening values in Mn–Cr–V–N steels, high nitrogen contents are advisable, but melting problems limit the amount to 0·2%. For higher amounts, the vanadium content should be about 0·7%. They should be quenched from 1100–1150° C. and tempered to approx. 700° C. Carbon content should be < 0·2%.

**Some Effects of Nitrogen in Cast Iron.** J. V. Dawson, L. W. L. Smith, and B. B. Bach. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1953, **4,** June, 540–552). It is possible to increase the nitrogen content of cast iron from 30 up to 500 p.p.m. by suitable treatment of the melt. The nitrogen has a pronounced stabilizing effect on pearlitic carbide in hypoeutectic and hypereutectic flake graphite irons and nodular irons. It also stabilizes eutectic carbide. Small additions of aluminium reduce the effect of nitrogen in malleable iron. Very high nitrogen contents cause porous castings.—B. G. B.

**Hydrogen in Cast Iron, Comparison with Steels.** P. Bastien. (*Fonderie*, 1953, Sept., 3579–3598). A comprehensive discussion of hydrogen in iron and steel with particular reference to cast iron. Among the aspects considered are : (*a*) The solubility and diffusion of hydrogen in iron ; (*b*) the analytical methods used for its determination in steels and cast irons ; (*c*) the causes of hydrogen pick-up ; (*d*) the effect of alloying elements on the solubility and diffusion of hydrogen in steels ; (*e*) the effect of hydrogen on the solidification of cast iron ; and (*f*) the effects of hydrogen on graphitization, mechanical properties, and the formation of internal blowholes.—B. C. W.

**Some Effects of Hydrogen on the Delayed Fracture of High-Tensile Steels.** Winifred A. Bell and A. H. Sully, (*J. Iron Steel Inst.*, 1954, **178,** Sept., 15–18). [This issue].

**On the Behaviour of Hydrogen in Steel.** M. Kawai. (*Tetsu to Hagane*, 1950, **36,** Dec., 604–608). [In Japanese]. Constants for the equations for solution and diffusion of hydrogen in steel are calculated, and embodied in a chart.—K. E. J.

**The Significance of Hydrogen in Steel Manufacture.** K. C. Barraclough. (*Murex Rev.*, 1954, **1,** (13), 305–348). Methods of determining hydrogen in steel are outlined and that used in the Brown-Firth Research Laboratories is described. The steel is heated at 650° C. *in vacuo* in a carbon crucible by means of a carbon resistance spiral. The gases involved are forced into a palladium tube at 600° C. and the diminution in volume of the gases when withdrawn is the hydrogen liberated. Diagrams of the apparatus and graphs of the rates of hydrogen evolution from several steels are given. The author then considers the sampling of liquid steel for hydrogen determinations and compares the notched pencil and sealed mould methods. The average values for the hydrogen contents of various steels at tapping when produced by different processes are listed and discussed. The effects of hydrogen on the solidification of liquid steel, and on the structure and mechanical properties of solid steels are discussed in detail and illustrated by graphs, sulphur prints, and photographs.—(13 references).—L. E. W.

**Study on the Effect of Various Gases upon Graphitization of Pig Iron.** M. Yoshida. (*Tetsu to Hagane*, 1950, **36,** Aug., 337–340). [In Japanese]. Repeated treatments with $H_2$, CO, $CO_2$, $O_2$, and $N_2$ at 1250° C. were performed. Hydrogen promoted graphite flake formation initially, but long, fine cementite was formed eventually. CO, $CO_2$, and oxygen promoted the fine eutectic graphite structure. Nitrogen gave graphite flakes in the pearlite. Combinations of the gases were also investigated.—K. E. J.

**The Effects of Gases on Cast Iron.** S. Maekawa. (*Tetsu to Hagane*, 1950, **36,** May, 180–183 ; June, 246–252). [In Japanese]. Sampling for hydrogen needs a very careful procedure, based principally on complete chilling of the sample. A deoxidizer is not needed, and the surface of the sample need not be finished. The effects of gases and other substances on the graphitization of cast iron in various states were examined ; in general, FeO, nitrogen, and hydrogen hinder graphitization. Strength increases and toughness decreases with increasing nitrogen and hydrogen. Sand and hydrogen promote the flaky graphite structure, while FeO and nitrogen promote the abnormal fine structures.—K. E. J.

**Vanadium-Bearing High Tensile Weldable Steels.** (*Welding Res.*, 1953, **7.** Oct., 103*r*–107*r*). The effect of vanadium (in

place of molybdenum) on the mechanical properties and weldability of high-tensile steel has been studied. In a normalized and tempered weldable steel (0·15% C, 0·9% Mn, 0·6% Ni, 0·9% Cr, 0·22% Mo) the molybdenum can be replaced by a smaller amount (about 0·14%) of vanadium with no loss in proof stress.—U. E.

**Vanadium as Replacement for Molybdenum in Low-Alloy Steels.** C. L. M. Cottrell and B. J. Bradstreet. (*Brit. Welding J.*, 1954, **1,** Feb., 82–86). Results are given of an investigation on the effect of substitution of molybdenum by vanadium in low alloy steels. A much lower transition temperature combined with much higher values of proof stress (0·02%) without adversely affecting the weldability of the steel has been obtained. The results apply to plates normalized under conditions equivalent to 1½ in. thick sections. Similar improved properties could probably be obtained with molybdenum steels by tempering them at about 600° C.—U. E.

**Some Aspects of the Effect of Copper in Cast Iron and Steel.** J. A. McNicol. (*Australasian Eng.*, 1953, Oct. 7, 54–60). Existing knowledge on the effect of copper additions to iron and steel is reviewed. Improvements in mechanical properties due to precipitation hardening, and improvements in corrosion resistance are discussed in detail. It is concluded that there is wide scope for copper-bearing materials in the iron and steel industry.—(17 references).—P. M. C.

**On the Effect of Each Element on the Temper Softening of Tool Steel for Hot Working.** S. Koshiba. (*Tetsu to Hagane*, 1950, **36,** Dec., 614–618). [In Japanese]. The effects of carbon, chromium, tungsten, and vanadium on the resistance to temper softening and high-temperature softening in special tool steel were ascertained. Comparisons are made with other types of alloy steel.—K. E. J.

**On the Mutual Relation Between Chromium and Tungsten in the Cr–W Tool Steel for Hot Working.** S. Koshiba. (*Tetsu to Hagane*, 1950, **36,** May, 211–215). [In Japanese]. The effects on tempering and quenching behaviour of increasing chromium and tungsten contents independently were elucidated for a tool steel containing C 0·25%, Mn 0·7%, and V 0·45%.—K. E. J.

**The Structure and Properties of Chromium Nitride and Ferrochromium.** M. L. Korolev. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Tekhnicheskikh Nauk*, 1953, (10), 1465–1470). [In Russian]. The influence of nitrogen on the properties of chromium steels is briefly reviewed. The properties of chromium and ferrochromium containing nitrogen were investigated. In nitrogen–chromium alloys an acicular phase is present. This needle-like component is characterized by its very high hardness which is higher than that of the chromium carbides. It is assumed that this phase is a nitride compound. The nitride phase has a variable composition and, on heating, undergoes transformations accompanied by changes in hardness. The presence of nitrogen in the alloys investigated is related to transformations of the basic structure accompanied by the appearance of two hardness maxima. An increase in hardness at higher temperatures corresponds to an increase in hardness of the needle-like phase. It is assumed that the first maximum corresponds to the precipitation of nitride phases and the second to the transformation of a nitride phase.—V. G.

**The Load-Deflection Relationship for a Partially Plastic Rolled-Steel Joist.** J. W. Roderick. (*Brit. Welding J.*, 1954, **1,** Feb., 78–82). The simple plastic theory of mild-steel structures, based on an idealized stress/strain relationship, is shown to be unsatisfactory for accurate calculation of deflections in structures loaded beyond the limit of proportionality. A theory is put forward which takes account of the true stress/strain relationship and is in good agreement with observed deflections of simply-supported rolled steel joists when these are loaded in the plastic range.—U. E.

**Cast High Alloys.** E. A. Schoefer. (*Chem. Eng.*, 1953, **60,** Oct., 298–314). These alloys contain 8% or more of nickel and/or chromium and are used for pumps and valve parts in such industries as petroleum refining and food handling. Tables are given of alloy specifications and physical and mechanical properties. Individual alloy characteristics and the problems of alloy selection to resist a particular corrosive attack are considered.—A. G.

**How Cold Reduction Affects General Properties of 18/8 Stainless Steel Wire.** S. Storchheim. (*Wire and Wire Prod.*, 1953, **28,** Dec., 1310–1311, 1314). Experiments are reported in which the effect of cold drawing up to 92 and 98% reduction of area on the ultimate tensile stress, resistivity, remanence, and coercive force, were measured. Three compositions of the nominal 18/8 type were examined, the base was annealed and non-magnetic.—J. G. W.

**Graphitic Steel.** V. Oliverius. (Reports of Czech Foundry Research : *Slévárenství*, 1954, **2,** (2), Supplement). [In Czech]. The influence of chemical composition and heat-treatment on the graphitization, mechanical properties, and wear of graphitic steels was studied in detail. It is concluded that normalizing and hardening followed by tempering below 500° C. gives best results. The steel is then almost entirely pearlitic or martensitic. Wear resistance did not appear to be in any obvious way related to hardness or chemical composition within wide limits, but depended upon the amount of carbon in solid solution.—P. F.

**Tool Steels.** J. Apraiz. (*Bol. Min. Industr.*, 1953, **32,** Dec., 602–607 ; 1954, **33,** Jan., 15–23). [In Spanish]. The author classifies tool steels and discusses their mechanical properties in relation to the influence of carbon content, heat-treatment, depth hardenability, and the effects of small amounts of vanadium and chromium.—R. S.

**On the Investigation of the Hot Working Tool Steels (I).** M. Tagaya, A. Adachi, and T. Ito. (*Tetsu to Hagane*, 1950, **36,** Aug., 349–356). [In Japanese]. The effects of some alloying elements and the carbon content, and mechanical properties at various temperatures, were investigated for W–Cr–V steel for use in forming presses.—K. E. J.

**Study on the Spring Materials.** H. Hotta. (*Tetsu to Hagane*, 1950, **36,** July, 322–325 ; Dec., 609–613). [In Japanese]. Tensile, hardness, microstructure and compression measurements at various temperatures showed that W–Cr steel was better than Si–Mn steel or 13%-Cr steel for parallel slide valves. Further tests, including forgeability, confirmed these results, and placed 18/4/1 W–Cr–V steel next in order of merit.—K. E. J.

**Studies on the Flake-Like Defects in Steel.** Y. Shimokawa. (*Tetsu to Hagane*, 1950, **36,** May, 189–206 ; June, 256–263 ; July, 311–317 ; Oct., 486–494). [In Japanese]. If soft steel containing 0·1–0·2% C is pickled and broken immediately, 'fish-eye' defects are found in the fracture. These and the tensile properties vary little with heat-treatment or pickling time. The defect is not caused by pickling, and vanishes on standing or boiling. With high-carbon steel, flake-like defects are produced in the same way as for special steels after water quenching, but not after oil quenching. As tempering temperature is raised, the appearance of the defects varies from flaky to 'fish-eye'. Experiments involving stress before and after pickling gave inconclusive results concerning defect formation : however, outer stresses higher than a given value appeared to be essential for flake formation with steel supersaturated with hydrogen, and the effects of small inner notches appeared to be very important. Flake formation is prevented by notches engraved on tensile and bending test pieces during fracture of pickled Izod and Charpy test pieces, and when pickled test pieces are fractured by shock, as opposed to slow breaking. The essential factors for flake formation include an inner stress due to concentrated molecular hydrogen and the outer stress. (15 references).—K. E. J.

**How to Select Your Materials.** H. W. Van der Hoeven. (*Chem. Eng.*, **60,** Aug., 202–208). The process conditions affecting choice of material are outlined, namely composition of mixtures, temperature, pressure, rate of flow, and impurities. Material properties such as machinability, creep strength, and corrosion strength are then considered, and the experimental conditions of corrosion tests are described. Examples are discussed to illustrate the points raised.—A. G.

**Equipment for Testing the Stiffness of Springs.** O. Göttfert. (*Draht, English ed.*, 1953, June, 31–37 ; Sept., 31–35). This is a survey of the principles of construction of specialized spring testing equipment, followed by a description of spring testing machines available in Germany.—J. G. W.

**High Chromium Cast Iron.** J. Wojcik. (*Przeglad Odlewnictwa*, 1954, **4,** (2), 39–45). [In Polish]. Iron-chromium and iron–chromium–carbon systems are outlined. The physical, chemical, mechanical, and casting properties of high-chromium irons are discussed. Uses for high-chromium iron castings are given.—V. G.

**The Chemical Composition and Mechanical Properties of Nodular Cast Iron.** J. Kol. (*Metalen*, 1954, **9,** Jan. 31, 17–21;

Feb. 15, 34–38). [In Dutch]. The composition and heat-treatment of nodular cast iron are discussed and figures are given of the permissible percentages of carbon, silica, manganese, and phosphorus to obtain the optimum tensile strength and elongation. Tables and curves are reproduced for material as-cast and after heat-treatment. As the wall thickness of the material increases the tensile strength and Brinell hardness decrease. (29 references).—F. R. H.

**Experimental Investigation of Torsion in Stranded Mining Wire Ropes.** C. L. Layland, A. R. S. Rao, and H. A. Ramsdale. (*Proc. Inst. Mech. Eng.*, 1952–53, **1B,** (8), 323–336). The torsional properties of wire ropes of two different constructions and sizes from $\frac{1}{2}$ to $\frac{7}{8}$ in. in dia. have been studied in great detail. Light is thrown on the difference between the properties of Lang's lay and ordinary lay, between long and short lay-pitch, and between few and many wires.—P. M. C.

**Consett Iron Company Limited: Test House.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 94). The Consett development scheme has included a new test house, placed so that routine inspection of materials can be carried out with a minimum of delay and transport. A brief description is given of the equipment.—G. F.

**Soviet Standards for Metallurgical Products.** M. Sykora. (*Normalisace* (Prague), 1952, 100–103 : *Met. u. Giesserei Techn.*, 1954, **4,** Jan., 27–28). The system of standardization in the U.S.S.R. is briefly explained. Before 1940 standards were called OST, now they are referred to as GOST. These letters are followed by group of figures to indicate the number of the standard and the year in which it was published. Specifications normally cover chemical composition and mechanical properties. U.S.S.R. standards distinguish between 500 types of steel and iron.—L. J. L.

**On the Possibility of Drawing up Standards for Steels in the East German Republic.** H. Säurich. (*Met. u. Giesserei Techn.*, 1954, **4,** Jan., 25–27). Suggestions made from time to time since 1943 that authoritative standards for steel be drawn up on the basis of the chemical composition of the steels have been embodied in the list of standards for iron and steel (S.E.S.). This list lays down specifications for all steels available in the East German Republic, for the guidance of producers and consumers.—L. J. L.

## METALLOGRAPHY

**An Example of Transference of the Laws and Phenomena of Metallography: from Light Aluminium Alloys to Heat-Resistant Austenitic Alloys.** A. Portevin. (*Rev. Mét.*, 1953, **50,** Dec., 811–816). The importance of applying knowledge gained in one field to another is illustrated by the progress made in austenitic heat-resisting steels as a result of a study of light alloys. Many other metallurgical and industrial examples of such transfers are mentioned.—A. G.

**The Electron Microscope and Its Application to Metallurgy.** V. A. Pickles. (*Australasian Eng.*, 1953, Oct. 7, 61–69). A brief review of the theory of light optics and electron optics is given. Limit of resolution is discussed, and the development of various types of electron microscope, (transmission, emission, and reflecting) is outlined. The examination of metal surfaces by replication is then dealt with ; various methods and types of replica are described and the shadowcasting technique is outlined. Etchants and etching methods necessary before replica preparation are discussed, and many examples of the uses of the electron microscope in metallurgical studies are quoted. (45 references).—P. M. C.

**A New Steroscopic Microscope.** K. Walz. (*Draht, English ed.*, 1953, June, 45–47). A new binocular low-power microscope by Zeiss is described and illustrated.—J. G. W.

**Evaporated Carbon Films for Use in Electron Microscopy.** D. E. Bradley. (*Brit. J. Appl. Phys.*, 1954, **5,** Feb., 65–66). Carbon evaporated on to an extremely soluble substrate, which is dissolved away, leaves very thin films suitable for electron microscope specimen supports.—J. O. L.

**Plated Electron-Microscope Specimen Screens.** F. W. Bishop. (*Rev. Sci. Instruments*, 1953, **24,** Oct., 986). To identify the specimen side of nickel screens, this side was plated by evaporating on to it a thin film of gold or copper.

**The Investigation of Metal Surfaces by Means of the Electron Microscope, with the Help of Silicon Monoxide Evaporated Replicas.** H. Wilsdorf. (*Z. Metallkunde*, 1954, **45,** Jan., 14–22). A method is described of evaporating silicon monoxide *in vacuo* directly on to the specimen, and removing it with or without lacquering, in some cases with wax as a stiffener. A number of applications of the technique are given and illustrated.—L. D. H.

**Direct Examination of Metals by Transmission to an Electron Microscope.** R. Castaing and P. Laborie. (*Compt. Rend.*, 1953, **237,** Nov. 23, 1330–1332). The method of electrolytically polishing a metal plate until thin enough for observation is described and its disadvantages considered. A new technique is described in which, after preliminary thinning, the plate is bombarded by a parallel beam of mono-kinetic ions and examined periodically with an electron microscope.

**The Effect of the Finite Light Sources of Measuring Instruments on the Determination of Electron Diffraction Ring Radii.** G. D. Orchard. (*Brit. J. Appl. Phys.*, 1954, **5,** Feb., 69–71).

**Attenuation of Gamma Rays. I—Transmission Values for Finite Slabs of Lead, Iron, and the Compton Scatterer.** G. H. Peebles. (*J. Appl. Phys.*, 1953, **24,** Oct., 1272–1287). Recursion formulæ have been developed and used to calculate the transmissions with one, two, and three scatterings for photons incident on slabs of lead and of iron, and from these calculated transmissions the 'build-up' factors have been estimated. The 'build-up' factor for normally incident photons of 1 to 20 $mc^2$ (m = electron mass, c = velocity of light) are given for lead slabs and for iron slabs having a thickness of 0 to 20 mfp. (mean free path). A second method, which considers the transmission through a thick slab as a succession of transmissions through thin slabs, is used to check the estimates of the 'build-up' factor obtained by the first method. This second method provides additional information in the form of the distributions of the transmitted photons.—J. O. L.

**Mitsche-Reichert Measuring Eyepiece for Determining Grain Size, Slag Inclusions, and the Like.** (*Jernkontorets Ann.*, 1953, **137,** (11), 816–818). [In Swedish]. The eyepiece consists of a Ramsden ocular having $\times 10$ magnification. The housing contains two revolving plates, each having 12 peripheral openings for glass reticules bearing various crystal sizes, regular hexagons in shape, with reticule sizes corresponding to the A.S.T.M. or Swedish J.K.M. scales. One disadvantage is that the recticule and the specimen exhibit the same colour ; comparison would be easier if the lines were a different colour.

**Grain Growth Characteristics of Some Constructional Alloy Steels.** T. Mishima and T. Mitsuhashi. (*Tetsu to Hagane*, 1950, **36,** Feb., 51–53 ; Mar., 113–115). [In Japanese]. Austenite grain size was found to be smaller in the double quenching method than in the McQuaid (cementation) test, many segregation grain boundaries being also found. These are the effective boundaries in steels containing hard soluble carbides. The fracture test for quenched specimens gives misleading results for grain size when carbon content is $< 0{\cdot}4\%$. It also gives smaller values than the McQuaid test. (13 references).—K. E. J.

**A New Microscope Principle.** J. M. Cowley. (*Proc. Phys. Soc.*, 1953, **B66,** Dec. 1, 1096–1100). A high-resolution image may be derived from a large number of 'dark field' images of normal resolution, obtained by varying the angle of incidence of the beam in a standard electron microscope. The practical applications are limited by requirements of specimen and instrument stability.—K. E. J.

**X-Ray Investigation of Textures of Low Carbon Steels.** Z. Bojarski. (*Prace Instytutow Ministerstwa Hutnictwa*, 1953, **5,** (5), 285–290). [In Polish]. A survey is made of the literature on the subject of textures produced by rolling and recrystallization of iron and low carbon steel. X-ray investigations of textures of low-carbon steel reduced 50% and 93·7% by cold rolling were carried out. Pole figures for the $\{110\}$ planes presented show that the texture is a function of the degree of deformation. The type of rolling texture determined by the author is in satisfactory agreement with that found by other investigators. The type of recrystallization texture found agreed with the results obtained by Kudryumov, Sachs, and Gensamer and Lustman, and does not change within the temperature range 690–925° C. Recrystallization annealing in the range 690–800° C. has no noticeable effect on the texture, whereas on annealing at 925° C. the grains tended to transform into a state of static disorder.—V. G.

**Structure of Austenite-Graphite Eutectic Grains.** K. P. Bunin, Ya. N. Malinochka and S. A. Fedorova. (*Liteĭnoe Proizvodstvo*, 1953, (9), 25). [In Russian]. The spatial shape of graphite grains in the austenite-graphite eutectic of a

hypo-eutectic cast iron was elucidated by the microscopical examination of sections produced at increasing depths in the same specimen. The fine eutectic grains formed by severe supercooling may consist of an austenite matrix containing a single large graphite grain of complex shape.—S. K.

**Radiographic Studies of Segregates.** A. M. Portevin. (*Metal Progress*, 1953, **64,** Dec., 108–110). Details are given of a method of studying dendritic segregation in steels. The sample is exposed to neutron bombardment in an atomic pile for 48 hr. after which an auto-radiograph of the surface can be obtained. A number of photographs taken by this new technique are given.—B. G. B.

**Microphotometer for the Radiographic Analysis of Crystals.** L. Cavalca. (*Ric. Sci.*, 1953, **23,** Sept., 1586–1592). [In Italian]. The author describes a photometer, basically very similar to that of Bezzi. The instrument is especially suitable for the measurement of diffraction intensities of the Wiebenga and Smits photographs. The instrument can be readily constructed with the facilities available in most laboratories.

**Ferromagnetic Study of Polycrystalline and Monocrystalline Cementite.** P. Blum and R. Pauthenet. (*Compt. Rend.*, 1953, **237,** Dec. 9, 1501–1502). The earlier low-temperature study of the saturation magnetization of polycrystalline cementite has been repeated at 20·4° K. and supplemented by measurements in the region 500° K. An axial extraction method was employed and results are compared with those for single crystals of cementite.—A. G.

**Irregularities in the McQuaid Ehn Grain Size of Austenite Grains.** Achard. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (1), 131–138). The effect of alloying elements, nitrides, and fine inclusions, on grain growth is discussed. Results of a study of grain growth of carbon steels are presented. Irregularities in the McQuaid Ehn grain size are due to the bad position of the growth/temperature curve in relation to the testing temperature (925° C.). In view of the sensitivity of the curve to a number of factors, its displacement in a suitable direction must be effected empirically.—A. G.

**The State of the Carbon in Austenite and Martensite as Revealed by the Eggertz Tests.** F. C. Thompson and A. R. Chaudhuri. (*J. Iron Steel Inst.*, 1954, **178,** Sept., 44–50). [This issue].

**Sigma Phase in Stainless Steel.** S.-E. Erikson. (*Svetsaren*, 1953, (3), 33–35). [In Swedish]. Tests on two weld metals (18/8/2·5 Cr–Ni–Mo and 25/20 Cr–Ni steels), the former containing 2% and the latter 0·05% ferrite before annealing, indicated that the ferrite content did not affect the formation of sigma phase. Very long annealing times (*e.g.*, 500 hr.) at as low a temperature as 620° C. did produce marked brittleness in the above Cr–Ni–Mo steel.—R. A. R.

**Some Notes on the Microstructures of Enamelled Iron Castings.** E. R. Evans. (*Brit. C.I. Res. Assoc., J. Res. Dev.*, 1953, **5,** Aug., 15–18). Microspecimens have been prepared from vitreous enamelled cast-iron test plates. Four specimens chosen as typical of a number examined are described; probable reasons for the occurrence of the structures are suggested.—B. G. B.

**The Mechanical Transformation of Weissenberg Pictures to Undistorted Theta Lattices.** J. O. Artman. (*Rev. Sci. Instruments*, 1953, **24,** Sept., 872–873). By means of the apparatus described, the diffraction spots are photographed on a $\theta$ lattice (*i.e.*, the distance from the origin to any spot is proportional to $\theta$, instead of to sin $\theta$ as in the reciprocal lattice). This retains the coverage of the Weissenberg pictures.—L. D. H.

**A Low-Temperature Weissenberg X-Ray Camera.** H. Steinfink, J. Ladell, B. Post, and I. Fankuchen. (*Rev. Sci. Instruments*, 1953, **24,** Sept., 882–883). A modified X-ray camera is described which permits the mounting or removal of the camera without disturbing the stream of cold gas in low-temperature work.—L. D. H.

**A Shielding Device for X-Ray Diffraction Cameras.** S. C. Abrahams and W. R. Blackmore. (*Rev. Sci. Instruments*, 1953, **24,** Sept., 885). The apparatus described consists of a double collar making an unbroken connection between the X-ray tube and the camera, and preventing scattering.

**An Automatic X-Ray Reflection Specimen Holder for the Quantitative Determination of Preferred Orientation.** W. P. Chernock, M. H. Mueller, H. R. Fish, and P. A. Beck. (*Rev. Sci. Instruments*, 1953, **24,** Oct., 925–928). The holder has a rapid alignment jig, two specimen-scanning devices, and it operates and records automatically.—L. D. H.

**The Development of a Fine-Focus Flash X-Ray Tube.** E. L. Criscuolo and D. T. O'Connor. (*Rev. Sci. Instruments*, 1953, **24,** Oct., 944–948). The design of an X-ray tube for high-speed radiography is described. Improved definition is obtained by the use of a conical tungsten target.—L. D. H.

**An Integrating Photometer for X-Ray Intensity Measurements.** E. Alexander, B. S. Fraenkel, A. Many, and I. T. Steinberger. (*Rev. Sci. Instruments*, 1953, **24,** Oct., 955–960). This instrument scans the surface of the diffraction spot, and integrates its intensity automatically.—L. D. H.

**Extinction in X-Ray Diffraction Patterns of Powders.** A. R. Long. (*Proc. Phys. Soc.*, 1953, **B66,** Dec. 1, 1003–1008). Formulæ are proposed for correction for the reduction of reflecting power of small spherical crystals due to primary and secondary extinction.—K. E. J.

**Secondary Recrystallization Textures in Mild Steels.** R. Guihaumé, M. Sternberg, and P. Lacombe. (*Compt. Rend.*, 1953, **237,** Oct. 19, 904–906). The successive recrystallization observed in metals such as copper and aluminium have now been detected in mild steels under certain conditions. The incubation period is very dependent on initial composition and the orientation of the crystals eventually formed may be loosely described by the texture (110) [001] with the (110) plane parallel to the rolling plane, and the [001] direction parallel to that of rolling.—A. G.

**Uniform Plastic Bending of Crystals for Focussing X-Ray Radiation.** L. S. Birks and E. J. Brooks. (*Rev. Sci. Instruments*, 1953, **24,** Oct., 992). A method is described for bending uniformly single and other crystals by pressing between a convex die and a tennis ball.—L. D. H.

**A Proportional-Counter Technique for Measuring X-Ray Scattering from Powders, Fibres, and Liquids.** U. W. Arndt, W. A. Coates, and D. P. Riley. (*Proc. Phys. Soc.*, 1953, **B66,** Dec. 1, 1009–1016). Counter spectrometers are described for the accurate semi-automatic measurement of diffracted X-ray intensity over scattering angles from 0 to 130°. (10 references).

**A Simple Method for the Precision Measurement of Lattice Constants.** H. J. Goldschmidt. (*J. Sci. Instruments*, 1954, **31,** Mar., 82–83). Lattice spacings on X-ray powder photographs are determined directly by mounting the film on a 9-in. dia. frame, to reproduce its position in the camera ; the angles are measured directly by a goniometer mounted co-axially with the frame. An accuracy equal to that given by a precision travelling microscope is obtained.—L. D. H.

**Application of X-Ray Diffraction to Metallurgical Problems.** Jose L. Amoros. (*Tecnica Metalurgica*, 1952, **8,** Oct., 325 332). [In Spanish]. The author reviews the study of stresses and fractures, and heat-treatment control, using X-ray diffraction. He outlines the advantages and limitations of this method and describes tests carried out.—R. S.

**The Interpretation of Diffuse X-Ray Scattering from Powder Patterns of Solid Solutions.** P. A. Flinn, B. L. Averbach, and P. S. Rudman. (*Acta Crystallographica*, 1954, **7,** Feb. 10, 153–158). [In English]. A modified form of the diffuse X-ray scattering from polycrystalline samples is used to obtain with a minimum of false detail, the Fourier coefficients which measure the local order and the size of atoms in solid solution. Two experimental examples (Al–Zn and Ni–Au) are considered.—B. C. W.

**Electron Diffraction Studies of Structural Changes Occurring During the Secondary Hardening of Low-Alloy Boiler Steels.** F. Králík. (*Hutnické Listy*, 1954, **9,** (2), 77–82). [In Czech]. It is shown, on the basis of electron diffraction evidence, that the precipitation of the carbides $V_4C_3$ and $Mo_2C$ in the range 450–700° C. is the most important cause of secondary hardening in the six types of low-alloy boiler steel studied (copper-brazing steels containing various combinations of nickel, chromium, molybdenum and vanadium). Nucleation and growth of precipitates to critical size did not appear to take place, and microsegregation from the initial matrix of the martensitic–bainitic structure directly out of the solid solution occurred during the initial stages of precipitation, the electronographic phase analysis, made during the period of internal change, confirmed that segregation was in fact responsible for the initial increase in hardness. The development of crystallographically well-defined submicroscopic precipitates eventually leads to a fall in the hardness.—P. F.

**The Beilby Layer.** B. Lunn. (*Z. Metallkunde*, 1954, **45,** Feb., 92–93). Recent work on the nature of the Beilby layer shows that it consists of a mixture of oxide and metal. The properties of the layer are explained and its significance in the action between bearing surfaces is emphasized.—L. D. H.

**Take Guesswork Out of Grain Size Determinations.** R. F. Harvey. (*Steel*, 1954, **134,** Feb. 1, 108–109). A new technique is described and illustrated with which the grain size of hardened and tempered high-speed steel can be measured by bringing out grain boundaries. The method consists of rehardening below the grain coarsening temperature on the second austenitizing treatment followed by Nital etching.

**An Electron Diffraction Apparatus with a New Electron Optical System Designed for the Examination of Surface Structure.** C. S. Lees. (*J. Sci. Instruments*, 1954, **31,** Mar., 84–86). A new electron optical system is described for use particularly with reflection specimens, in which inaccuracies introduced by a convergent incident beam are avoided by the use of a strictly parallel beam. The half-rings obtained are accurately focused, and the specimen can be turned through 180°, allowing the diametrically opposite part of each ring to be photographed. By this means measurements can be made across diameters.—L. D. H.

**Structure and Properties of Solid Surfaces.** R. Gomer and C. S. Smith [Editors]. (*Conf. on Structure and Properties of Solid Surfaces*, University of Chicago Press and Cambridge University Press, 1953). This 491-page book reports the proceedings at the conference organized by the Committee on Solids of the National Research Council, held at Lake Geneva, Wisconsin, in September 1952. The papers presented were :

**The Use of Classical Macroscopic Concepts in Surface-Energy Problems.** C. Herring. (5–81).

**Atomic Theory of Surface Energy.** P. P. Ewald and H. Juretschke. (82–119).

**The Mechanical Properties of Crystalline Metal Surfaces.** A. J. Shaler. (120–146).

**Wetting of Solids As Influenced by the Polarizability of Surface Ions.** W. A. Weyl. (147–184).

**The Study of Solid Surfaces.** G. P. Thomson. (185–202).

**The Adhesion of Solids.** F. P. Bowden and D. Tabor. (203–239).

**Crystal Growth and Chemical Structure.** A. F. Wells. (240–270).

**Some Remarks on Facts and Theories of Crystal Growth.** H. E. Buckley. (271–317).

**Epitaxy.** H. Seifert. (318–383).

**Physical Adsorption of Gases on Solids.** T. L. Hill. (384–399).

**Surface Structure from the Standpoint of Chemisorption and Catalysis.** M. Boudart. (400–413).

**Physical and Chemical Adsorption of Gases on Iron Synthetic Ammonia Catalysts.** P. H. Emmett. (414–438).

**Chemisorption on Solid Surfaces.** A. Wheeler. (439–463).

**The Catalytic Action of Spinels.** G.-M. Schwab, E. Roth, Ch. Grintzos, and N. Mavrakis. (464–477).

**New Methods Determine Grain Size Ultrasonically.** N. Grossman. (*Iron Age*, 1953, **172,** Dec. 31, 72–75). A series of experiments showing the relationship between grain size and the transmissibility of ultrasonic waves through brass rods are described. It is shown that for ratios below 1 : 10 the transmission quality diminishes rapidly, and it is suggested that this method can be used to determine the grain size of products in a non-destructive manner.—A. M. F.

**The Movement of Individual Atoms in Metals.** R. S. Barnes. (*Science News No.* 29, pp. 32–44 : Penguin Books Ltd., Aug., 1953) The author introduces the concept of lattice structures and defines diffusion, self-diffusion, and interdiffusion. The methods of measuring diffusion rates are also outlined. The three possible ways in which an atom can change its lattice position—by direct interchange, by interstitial, and by vacancy mechanisms—are considered and illustrated. Movement along grain boundaries is dealt with and the nature of dislocations is discussed.—L. E. W

**On the Existence of the Ferrite $CaO.2Fe_2O_3$.** J. Maliquori and V. Cirilli. (*Chim. e Indust.*, 1953, **35,** Oct., 737–740). [In Italian]. The authors give a brief description of the work which has lead them to confirm their previously published statement on the non-existence of the ferrite $CaO.2Fe_2O_3$. From spectrographs obtained with an X-ray spectrometer equipped with Geiger counter it appears that the hypothetical compound $CaO.2Fe_2O_3$ is nothing but a mixture of monocalcic ferrite and ferric oxide. (14 references).—M. D. J. B.

**X-Ray Studies of Polycrystalline Metals Deformed by Rolling. III. The Physical Interpretation of the Experimental Results.** P. Gay, P. B. Hirsch, and A. Kelly. (*Acta Crystallographica*, 1954, **7,** Jan. 10, 41–49). [In English]. The results of experiments on the structure of cold-rolled polycrystalline metals are discussed in terms of dislocation theory. It is suggested that the grains within a cold-worked metal contain a 'foam' structure of relatively perfect particles linked continuously with each other by distorted boundary regions. The latter correspond to the slip bands while the particles are the regions between the slip bands. Recovery is explained by the rearrangement of the dislocations in the boundaries to reduce the strain energy, and recrystallization is considered to occur when the number of excess dislocations of one sign exceeds a limiting value. The results obtained are also discussed in relation to the process of deformation, X-ray line broadening, and the strength of metals.—B. C. W.

**The Diffusion of Cobalt, Chromium, and Tungsten in Iron and Steel.** P. L. Gruzin. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (4), 681–684). [In Russian]. The temperature dependence of the coefficients of diffusion of cobalt, chromium, and tungsten in the $\alpha$ and $\gamma$ phases of commercial iron and carbon steel of eutectoid composition was studied over the range 700–1250° C. The diffusion measurements were made using radioactive isotopes $Co_{60}$, $Cr_{51}$, and $W_{185}$. Assuming that the activation energy of diffusion and self-diffusion forms some part of the interatomic bond energy in the crystal lattice of a metal or solid solution, the following conclusions were reached: (1) Bonds between atoms of cobalt, chromium, and tungsten, and atoms of iron in the austenite lattice are stronger than bonds between irons atoms, since the energy of activation of diffusion of these elements is considerably higher than the energy of activation of self-diffusion in the austenite ; (2) the bond energy of the above elements in ferrite is noticeably lower than that in austenite ; (3) the solution of carbon in austenite leads to a noticeable lowering of the atomic bond energies for both carbide forming (W, Cr) and non-carbide forming (Co) elements. It can therefore be assumed that in austenite the bonds between metallic atoms are stronger than those with carbon.—V. G.

**Alloys.** G. L. Bailey. (*J. Roy. Soc. Arts*, 1954, **102,** Mar. 5, 227–276). This paper combines the three Cantor Lectures. In the first the author summarizes the basic facts concerning the structure of metals and in so doing discusses briefly the structure of the atom, substitutional and interstitial solid solutions, superlattices, and the interpretation of phase diagrams. The deformation of metals is dealt with in terms of dislocations, and recrystallization is also considered. The properties of metals and alloys associated with different types of structure are briefly discussed. The second lecture covers the industrial uses of pure metals, alloys for castings (with particular reference to volume changes on solidification, dissolved gases, and the properties of cast iron), and the increase in strength obtained by heat-treatment. In the last lecture the author outlines the principles of, and discusses alloys with creep and corrosion resistance.—L. E. W.

**Crystallographic Techniques in Industrial Chemical Analysis.** Jose L. Amoros. (*Tecnica Metalurgica*, 1952, **8,** Sept., 289–301). [In Spanish]. The four principal methods of studying crystallography are surveyed, namely : (1) Morphological examination by means of goniometry, (2) Optical examination using polarized light ; (3) X-ray determination using single crystals ; and (4) X-ray determination using powder photographs.—R. S.

**Studies of Continuous Phase Transformations with X-Rays.** E. Gillam and D. G. Cole. (*Phil. Mag.*, 1953, **44,** Sept., 999–1010). A method has been developed to study the progress of the transformation of austenite (*a*) into martensite as the temperature falls below the $M_S$ point, and (*b*) under isothermal conditions below the $M_S$ point. The martensite results do not agree completely with Cohen's empirical formula, while the isothermal results show the marked effects of alloying elements. **S**-curves below the $M_S$ point are drawn for the En steels 24, 26 and 30B. (14 references).—K. E. J.

**Factors Influencing the Isothermal Transformation of Austenite in the Intermediate Range (Bainite Range).** O. Schaaber. (*Draht, English ed.*, 1954, Feb., 19–25). Following a historical survey of the development of isothermal transformation diagrams and the discovery of bainite, austempering is explained, and the effect of the treatment on mechanical properties described, based mainly on German war-time investigations. Mention is made of the dilatometric method of determining the degree of austenite transformation.—J. G. W.

**The Influence of Elements Forming Carbides Difficult to Dissolve on the Decomposition of Austenite.** L. I. Kogan and R. I. Entin. (*Doklady Akdemii Nauk S.S.S.R.*, 1954, **94,** (4), 693–696). [In Russian]. The possibilities of increasing the stability of austenite with alloying elements which form carbides difficult to dissolve is discussed. The isothermal decomposition of steels alloyed with manganese and titanium was investigated. X-ray and chemical analyses were made of the electrolytically isolated carbide phases. It was shown that, in the presence of manganese, additions of vanadium, titanium, and other carbide-forming elements, are partly transferred to the austenite on heating, and the necessity for their redistribution by diffusion during subsequent decomposition results in a greater stability of the austenite in the pearlitic temperature range, particularly below the temperature of the maximum velocity of decomposition.—V. G.

**Hysteresis of the $A_3$-Transformation in Pure Iron.** E. Houdrement and O. Rüdiger. (*Stahl u. Eisen*, 1954, **74,** Feb. 11, 227). Measurement of the electron emission from evaporated iron films, heated to various temperatures, has shown that when the film is 50m$\mu$ thick, there is no hysteresis at the $A_3$-point but that hysteresis appears when the thickness is increased to 100m$\mu$. It is indicated that the $\gamma$–$\alpha$ change is delayed in thicker films and that film thickness and nucleation energy are responsible for the hysteresis.—J. P.

**Exposition of the Strain-Age-Hardening Problem of the Mild Steel.** K. Yoshizaki. (*Tetsu to Hagane*, 1950, **36,** Nov., 563–569 ; Dec., 622–626). [In Japanese]. The problem of strain-age-hardening is explained. Recent work shows that both carbon and nitrogen atoms in mild steel play a leading rôle, and ageing effects can be minimized by drastic deoxidation. The three important theories (skeleton, transformation, and dislocation theories) are outlined. (10 references).—K. E. J.

**The Effect of Transformation and Thermal Contraction on the Quenching Stress of Steel. (II).** T. Sugeno and K. Sakamoto. (*Tetsu to Hagane*, 1950, **36,** Nov., 548–555). [In Japanese]. In high nickel–iron alloys, when the $\gamma \rightarrow \alpha$ transformation is in the higher temperature range, the thermal contraction and the transformation expansion both contribute to the residual quenched stress ; in the elastic range, only transformation has an effect. Results are presented for cooling to liquid oxygen temperature, and for the size of section of the specimen. A theory for the mechanism of the origin of quenching stress is put forward.—K. E. J.

**On the Spheroidizing of Carbides in Steels. (I).** T. Sato and E. Yajima. (*Tetsu to Hagane*, 1950, **36,** Nov., 543–547). [In Japanese]. The effects of the particular elements on spheroidizing of carbides by tempering at various temperatures after quenching were examined in carbon steel and hyper-eutectoid steels containing 1% and 2% of Si, Ni, Cr, Cu, Mn, Al, Mo, Co, V or W. In steels containing elements which do not form special carbides, spheroidizing is not affected by the quenching conditions, or by undissolved carbides in the austenite at the quenching temperature. (14 references).—K. E. J.

**On the Migration of Austenite Grain Boundaries.** M. G. Lozinskii. (*Doklady Akademii Nauk S.S.S.R.*, 1952, **82,** (1), 53–56). The apparatus and procedure developed by the author for studying the kinetics of migration of grain boundaries are described.—V. G.

**Contribution to the Problem of the Austenite to Martensite Transformation.** G. A. Oding. (*Vestnik Mashinostroeniya*, 1952, **32,** (3), 69–71). Martensite transformation over the entire temperature range of transformation at a slow cooling rate (3° C./min.) was investigated using a dilatometric method. The steels studied were : (1) A 1·2%-C tool steel ; (2) a 1·4%-C, Mn–Cr steel ; (3) Si–Cr steel ; (4) a 1%-C, 1·5%-Cr steel for bearings ; and (5) Cr–W and Cr–W–Mn steels. It was found that the rate of transformation of austenite into martensite passes through a pronounced maximum at which less than 50% of the austenite has been converted.—V. G.

**A Contribution to the Constitution of the Ternary System Fe–Mn–C. Isothermal Sections at 1050°, 910°, and, 690° C.** K. Kuo and L. E. Persson. (*J. Iron Steel Inst.*, 1954, **178,** Sept., 39–44. [This issue].

**The Structure of Binary Alloy Systems of Titanium.** D. J. McPherson and M. Hansen. (*Z. Metallkunde*, 1954, **45,** Feb., 76–81). The structures of a number of binary alloys of titanium are described. In the case of the Ti–Fe system, it is stated that quenchable alloys must contain at least 3·1 to 4·1% Fe. TiFe has a space-centred cubic lattice of the CsCl-type, whilst $TiFe_2$ has a structure of the hexagonal $MgZn_2$ type. (97 references).—L. D. H.

**Investigation of the Composition/Heat-Resistance Diagram of Alloys in the Quaternary System Iron–Chromium–Nickel–Manganese.** I. I. Kornilov and K. A. Osipov. (*Izvestiya Akademii Nauk S.S.S.R., Otdelenie Khimicheskikh Nauk*, 1953, (3), 429–483). [In Russian]. Electrical resistance and hardness at room temperature and heat resistance at 800° C. of a section of the quaternary Fe–Cr–Ni–Mn system were investigated. From the data obtained it is concluded that, in many alloys based on the Fe–Cr–Ni system, manganese can replace a considerable proportion of nickel without substantially altering the resistance to plastic deformation. This replacement must, however, be accompanied by addition of elements which increase the heat resistance of the alloy.

## CORROSION

**Basic Concepts of Corrosion and Corrosion Protection.** O. T. Johannesen. (*Tekn. Ukeblad*, 1954, **101,** Jan. 28, 63–69). [In Norwegian]. After illustrating the reactions taking place in galvanic and differential aeration cells and during 'drop' corrosion, the author deals briefly with stray-current and stress corrosion, underground and atmospheric corrosion, and cites an instance of combined corrosion and erosion. Types of protective paints employed in American industry are described.—G. G. K.

**Designs for Corrosion.** A. W. Peabody. (*Proc. Amer. Gas Assoc.*, 1952, 408–413). Measures applied to combat corrosion in the gas industry are discussed, and the importance of considering these during initial planning of an installation is stressed.—D. L. C. P.

**Economics of Corrosion Control.** A. W. Peabody. (*Proc. Amer. Gas Assoc.*, 1952, 284–289). Measures for control of corrosion which are of concern to the gas industry are assessed descriptively, particularly the protection of mains and services. Coatings, insulation, and cathodic protection are covered. It is concluded that systems can now be designed to be corrosion free and that this should be done during the basic planning when possible.—D. L. C. P.

**Corrosion Testing by Measurement of Local Cell Potentials.** J. K. Rice. (*Corrosion*, 1954, **10,** Jan., 25–29). The measurement of local cell potentials has been applied to a study of the corrosion inhibition produced by hexametaphosphate on steel in water. The potential variations between a stationary micro-probe reference electrode and a rotating steel electrode are recorded on an oscillograph. Local anodes and cathodes can be examined by the method which has also indicated the existence of very high resistance films on the inhibited surface.—J. F. S.

**Protection of Steelwork from Atmospheric Corrosion.** F. R. Himsworth. (*Iron Coal Trades Rev.*, 1954, **168,** Feb. 19, 461–464). The author reviews the means available for protecting steelwork from atmospheric corrosion and discusses their relative merits. The preparation of the metal surface is first considered, and details are then given of paint protection and metal spraying. Data on the economics of these processes and of the possible savings in maintenance are also included.—G. F.

**Black Iron or Equivalent?** W. M. Myler, jun., (*Proc. Amer. Gas Assoc.*, 1952, 849–851). The author refers to reports of tests made at Batelle Memorial Institute, on the corrosion of various metals and fabrications by the products of combustion of gaseous fuels. Average penetration rate and maximum penetration (pitting) rate were differentiated. Several materials are reported as giving better results then mild steel.—D. L. C. P.

**Effect of Temperature Differences in the Electrolyte on the Corrosion of Iron.** W. Breckheimer and J. D'Ans. (*Werkstoffe u. Korrosion*, 1954, **5,** Feb., 43–48). The authors have studied the behaviour of cells consisting of two iron electrodes dipping into separate solutions of potassium chloride of the same concentration but at different temperatures. One half cell was heated to temperatures up to 85° C.; the other was kept at 15° C. When the solution was sufficiently concentrated, *i.e.*, 0·1*N*, 1*N*, or 3*N*, the hot electrode was always the anode and the cells produced sufficient current to protect the cold electrode cathodically. In more dilute solutions, *i.e.*, 0·01*N* and 0·001*N*, the current fell considerably, because of the high internal resistance of the cells, and both electrodes were attacked. The addition of sufficient potassium nitrate to the solutions reversed the polarity of the cells once the cold

electrode became the anode ; this is attributed to the formation of a passivating oxide film over the hot electrode.

**Possibility of Attack by Sulphuric Acid in Oil-Fired Boilers.** J. L. Mansa. (*Tekn. Ukeblad*, 1954, **101**, Jan. 14, 33–35). [In Danish]. Factors governing the corrosion of boiler heating surfaces at temperatures below 180° C. are outlined. The influence of sulphur in the fuel on flue gas dew point and the resultant danger of $H_2SO_4$ formation is described, curves showing the dew point as a function of $SO_3$ in the flue gas. Remedial measures include the injection of fly ash from pulverized-fuel-fired boilers into the combustion zone of an oil-fired unit, this serving to lower the dew point, perhaps by adsorbing the sulphur compounds. Typical instances of acid attack on tubes are illustrated.—G. G. K.

**Materials for Central Station Pumps.** J. B. Godshall. (*Corrosion*, 1954, **10**, Jan., 21–24). Corrosion–erosion in feed pumps has been substantially eliminated by using steels containing 5% or more chromium. The engineering aspects of their use are discussed. Chromium-plated case-hardened low-alloy steels are suitable for shaft sleeves. If dissolved gases are present, bronze or 13%-Cr steel is desirable. Stainless steels have certain applications in resisting sea water. Protective rubber coatings may lead to severe local attack if imperfect.—J. F. S.

**Laboratory Measurement of the Corrosion of Ferrous Metals in Soils.** W. J. Schwerdtfeger. (*Corrosion*, 1954, **10**, Jan., 30–36). A reproducible method for setting up soil corrosion cells is described. Weight losses of steel and cast iron electrodes after six months in the soil were related to weight loss and maximum pitting observed after 10 years' burial of wrought ferrous specimens in field tests. The empirical relationship may be used to predict weight loss and pitting after 10 years in any soil. Adjustments are suggested for other areas than that of the field specimens and for other exposure periods.—J. F. S.

**Soil Resistivity Instruments and Measurements.** O. W. Wade. (*Proc. Amer. Gas Assoc.*, 1952, 487–488). Methods of measuring the resistivity of soil *in situ* or sampled are described ; the value is important in corrosion problems.

**Corrosion Protection of Natural Gas Main in Greater New York.** F. E. Kulman. (*Proc. Amer. Gas Assoc.*, 1952, 376–392). This paper deals with the planning, installation, and testing of corrosion control measures for a new underground gas main. After considering the conditions and alternatives, a completely coated line was planned, with strategically placed insulating joints and cathodic protection by cast magnesium anodes. Detailed maps, diagrams, and figures are given.—D. L. C. P.

**Economics of Steel Service Pipe Protection.** C. L. Woody. (*Proc. Amer. Gas Assoc.*, 1952, 448–456). The comparative costs for a system of small steel service gas pipes under various conditions are considered by referring to experience and expectations on an actual installation. A series of curves represent the number of leaks plotted against time. The conditions for economic employment of coat- and cathodic-protection in the cases cited, are given.—D. L. C. P.

**Reduction of Condensate-Line Corrosion.** S. Jensen and E. R. Lang. (*Trans. Amer. Soc. Mech. Eng.*, 1954, **76**, 245–249). The authors report progress made in the reduction of copper and iron corrosion in boiler auxiliaries with ammonia, cyclohexylamine, morpholine, and sodium sulphite in the water. The reduction in corrosion in the condensate system of two typical American steam stations is discussed.—D. H.

**Effect of Coating Quality on the Corrosion Resistance of Galvanized Steel Wires.** J. Hérenguel. (*Rev. Mét.*, 1954, **51**, Jan., 36–44). A series of improperly galvanized carbon steel wires was subjected to the following tests : Estimation of coating thickness by various methods, examination of microstructure of the deposit, and analysis after progressive solution, estimation of brittleness, and an accelerated salt-spray corrosion test. It was concluded that : (1) The Preece test for estimating thickness is reliable ; (2) iron lowers ductility without impairing corrosion resistance ; and (3) there is good agreement between accelerated corrosion test results and the weight of deposit.—A. G.

**Corrosion and Cathodic Protection.** G. G. Portch and W. G. Waite. (*Coke Gas*, 1954, **16**, Jan., 19–23). The principles of galvanic corrosion, concentration cell corrosion, microbiological corrosion, and stray current corrosion are discussed and methods for preventing the corrosion of buried structures are considered. Buried iron or steel may be successfully protected by the use of a magnesium alloy anode, except in situations where the soil has a very high resistance. In this case transformer rectifiers can be used in conjunction with a graphite anode to maintain the buried structure at a sufficiently high electro-negative potential.—B. C. W.

**Cathodic Protection—Cathodic Protection in Relation to Engineering Design.** K. A. Spencer. (*Chem. Indust.*, 1954, Jan., 2–10). By suitable selection of protective coatings and attention to design, many structures can be cathodically protected economically. Some of the difficulties are outlined. Means of ensuring electrical continuity on pipelines and arrangements for test points are outlined. The effects on neighbouring structures are discussed. The protection of tank bottoms and jetties are similarly outlined. Cathodic protection can also be used, on occasion, for sheet piling, bridge footings, buoys and pontoons, ships (both externally and the interior of tankers), separators, and rotary chain screens, condensers, pumps, pylons, and underground cables.—J. F. S.

**Cathodic Protection—Development of Cathodic Protection in Belgium.** A. Weiler. (*Chem. Indust.*, 1954, Jan. 16, 56–63). In Belgium stray currents have been widely used to afford cathodic protection to adjacent buried pipelines and cables. The apparatus used to control the potential is described. Where necessary, the protection is supplemented by the use of impressed currents and by sacrificial anodes. The design of the apparatus varies according to the layout of the various systems.—J. F. S.

**Cathodic Protection—Cathodic Protection and Control of Corrosion in the Middle East.** W. C. R. Whalley. (*Chem. Indust.*, 1954, Feb. 6, 140–147). Severe corrosion of buried steel in the Middle East deserts occurs at saline patches and on the coasts. The waters of the Persian Gulf are more corrosive than those of the Levant Coast. Cathodic protection using rectifiers or, in remote areas, Diesel generators, is being used successfully to combat pipeline corrosion inland. Magnesium anodes are often used on the coastal flats and in the sea to protect jetties, submarine loading lines, and buoys. On tank-farms special difficulties arise. A coating to be used in conjunction with cathodic protection to prevent corrosion of tank bottoms is described.—J. F. S.

**Cathodic Protection—Its Application to Ships and Establishments of the Royal Navy.** J. T. Crennell. (*Chem. Indust.*, 1954, Feb. 20, 204–209). Ships in reserve and floating docks are being protected from underwater corrosion by magnesium anodes hung over the side. For jetties and sheet piling, an impressed current is preferred. Protection extends up to about half-tide level. Cathodic protection is considered unsuitable in fresh water. The silver/silver-chloride reference electrode and a ground voltmeter are described. High-purity zinc anodes have been tested successfully. Amalgamation of anode metals, the effect of cathodic protection on paint and antifouling, and the use of cathodic protection on aluminium and stainless steel are discussed.—J. F. S.

**Cathodic Protection—Economic Aspects of Corrosion Control.** D. H. Lewis and O. C. Mudd. (*Chem. Indust.*, 1954, Jan. 23, 93–100). Costs in the U.S.A. of buried pipelines are compared with costs of corrosion prevention. Reconditioning costs exceed cost of good initial coating and cathodic protection. The experience gained over many years of successful cathodic protection of coated pipelines is recounted and the economic factors influencing the selection of the method of protection are discussed with examples.—J. F. S.

**Cathodic Protection of the Interior of Cargo Compartments in Oil Tankers.** J. Lamb, E. V. Mathias, and W. G. Waite. (*North-East Coast Inst. Engineers and Shipbuilders, Advance Copy*, Mar. 26, 1954). Following a brief outline of the theory of cathodic protection, its successful adaption to oil tankers is considered. Factors which had to be taken into account by the authors in a large-scale trial on the 12,250-ton m.v. " Auris," and the results obtained, are discussed. Diagrams and photographs are included.—L. E. W.

**Stabilizing Austenitic Chrome-Nickel Weld Metal Against Intergranular Corrosion.** H. C. Campbell. (*Welding J.*, 1953, **32**, Dec., 577s–584s). Tests have been made using a 22%-Cr 10%-Ni electrode instead of the usual niobium addition to obtain a weld which will resist intergranular attack. Titanium additions were also studied. It was found that the chomium was more effective than titanium. All specimens were subjected to accelerated corrosion tests in boiling 65% $HNO_3$ and in mixed nitric and hydrofluoric acids at 180° F.—U. E.

**12% Chromium Stainless Steels.** Amer. Iron Steel Inst. Committee of Stainless Steel Producers. (*Chem. Eng.*, 1953, **60,** July, 262–272). These steels are resistant to wear and erosion and are hardened by heat-treatment which also affects the corrosion resistance. Data on composition and physical and chemical properties are given together with the resistance to corrosion by more them 100 reagents. Typical uses of these steels are outlined.—A. G.

**New Alloys Stop Corrosion in Silver-Brazed Type 430 Joints.** J. J. Halbig, L. H. Grenell, and G. H. Sistare. (*Iron Age*, 1953, **172,** Dec. 10, 159–163). Corrosion tests of brazed joints in 430 stainless steel are reported. It is believed that failures can be accounted for by a crevice corrosion mechanism. The presence of a nickel-rich interface seems to inhibit the progress of an expanding crevice, a brazing alloy containing nickel and a long brazing cycle to allow migration to take place are recommended. Soft solder flushing or nickel plating may also be used.—A. M. F.

**Corrosive Effects of De-Icing Salts.** (*Corrosion*, 1954, **10,** Jan., 3–6). In cities with heavy snowfall the de-icing salts used increase corrosion of cars, bridges, and other steel structures, and of underground pipes and cables. Remedial measures are considered.—J. F. S.

**Corrosion by Acids at High Temperatures.** R. F. Miller, R. S. Treseder, and A. Wachter. (*Corrosion*, 1954, **10,** Jan., 7–12). A simple apparatus for testing the corrosiveness of acids and other liquids above their normal boiling points is described. Corrosion data are presented for various metals in sulphuric, phosphoric, nitric, formic, and boric acids, and phenol. Stainless steels proved less resistant than copper at these temperatures.—J. F. S.

**Rust Hasn't a Chance.** C. O. Durbin. (*S.A.E. J.*, 1954, **62,** Jan., 30–33). Modern methods for the protection from corrosion of automobile parts during processing, shipping, and storage are described. The uses and applications of corrosion inhibiting compounds in processing liquids, wax and oil base slushing compounds, wrapping paper, and in strippable plastic films are enumerated with reference to current practice by the Chrysler Corporation.—P. M. C.

**Control Your Corrosion Costs.** L. R. Honnaker. (*Steel*, 1954, **134,** Mar. 22, 110–111). The types of metal corrosion are listed and described, and the principles of protection given.—D. L. C. P.

**Inhibitors of Atmospheric Corrosion.** S. A. Balezin and V. P. Barannik. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (2), 345–347). [In Russian]. Benzoate and carbonates of amino-alcohols and esters of complex organic compounds were tested as inhibitors of the atmospheric corrosion of ferrous metals. The results showed that many of these compounds protect carbon steel in humid atmospheres. The most effective were benzoates and carbonates of amino-alcohols. The testing method and some results are described.

**The Application of Reaction Kinetics to the Study of Corrosion.** T. G. Oweberg. (*J. Chim. Phys.*, 1953, **50,** Nov.-Dec., 617–623). The speeds of solution of metals such as copper, molybdenum, and iron in acid solutions have been measured. For the examples studied the factor limiting solution rate was either the adsorption of reagents on the metallic surface or the evolution of the reaction products.—A. G.

**On the Composition of the Photographically Active Substances Evolved by Metals During Atmospheric Corrosion.** I. L. Roikh. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (6), 1117–1120). [In Russian]. The nature of the photographically active substances evolved by metals during atmospheric corrosion was investigated. During atmospheric corrosion, molecules of hydrogen peroxide are evolved which act on the photographic plate.—V. G.

**On the Passivity of Iron in Concentrated Sulphuric Acid.** V. N. Novakovskii and A. I. Levin. (*Doklady Adakemii Nauk S.S.S.R.*, 1954, **94,** (6), 1113–1116). [In Russian]. A study of the corrosion of steel in concentrated sulphuric acid is described. A formula for the amount of dissolved metal is deduced which is in good agreement with experimental data.

**Prevention of Water Corrosion.** P. W. Sherwood. (*Min. Mag.*, 1954, **90,** May, 275–280). Some details are given of the principal means of reducing corrosive attack in mining work, *viz.* cathodic protection, metallic coatings, organic coatings, inhibitors, alteration of environment and metallurgical selection.—K. E. J.

**Corrosion by Water at Low Flow Velocity.** T. E. Larson and R. M. King. (*J. Amer. Water Works Assoc.*, 1954, **46,** Jan., 1–9). The past studies of water-corrosion and the current practice in the investigation of this problem are critically reviewed. Experiments are described which demonstrate the behaviour of solutions at corrosion cell electrodes and a possible explanation is provided for the inhibitory effect of bicarbonate and carbonate alkalinity. It is stressed that, without basic data on the primary, partial, or total inhibition of the natural corrosion inhibitor normally present, it is not possible to correlate observations made on the effectiveness of other inhibitors or methods of treatment against corrosion.

**Mechanism of the Internal Corrosion of Water Pipe.** R. Eliassen and J. C. Lamb III. (*J. Amer. Water Works Assoc.*, 1953, **45,** Dec., 1281–1294). The authors introduce briefly the theory of corrosion and describe the different types of corrosion cells that can be formed. Typical cells found in practice, and the conditions under which they occur, are discussed. The types of corrosion control available, and the factor affecting the rate and distribution of corrosion are dealt with.—L. E. W.

**Field Tests of Exterior Coatings for a Pipe Line Conveying Fuel Oil Heated to 200 Degrees F.** E. R. Stauffacher and R. R. Davidson. (*Corrosion*, 1953, **9,** Oct., 377–381). An asphalt wrap (0·25 in. thick) two coal-tar wraps (0·25 and 0·16 in.) and an asphalt mastic (0·50 in.) were compared on 20-ft. lengths of buried 8-in. pipe by circulating hot oil and at the same time applying pressures of 10, 50 and 80 lb./sq. in. at spots on the coatings. After test, the depressions in the coatings were examined for distortion, adherence, and electrical resistance. Cold bending tests on 40-ft. lengths of coated pipe were also used. The asphalt mastic was chosen as the best.—J. F. S.

**The Corrosion-Metallurgical Aspects of Sucker Rods and Their Oil Well Service Performance.** F. J. Radd and R. L. McGlasson. (*J. Petroleum Techn.*, 1954, **6,** Mar., 37–44). The mechanisms of damage by corrosion and corrosion fatigue to sucker rods are examined from a fundamental electrochemical viewpoint, and the relationships of sucker rod microstructures to these damaging effects are defined. The common corrosive agents in crude oil production and storage are discussed as to types of attack that they cause. The variations of fatigue strength with alloy content, surface preparation, and stress ranges are analysed. Finally, conclusions are drawn as to how microstructures largely influence and control sucker rod performance. (15 references).—L. E. W.

**Control of Internal Corrosion of Tankers.** W. B. Jupp and C. J. Lamb. (*J. Amer. Soc. Naval Eng.*, 1954, **66,** Feb., 152–165). Various methods of corrosion control and their effectiveness under different conditions are discussed. The authors conclude that : (1) The use of special anti-corrosive steel extends the life more than 25%. (2) Dehumidification, chemical treatment of the tanks, and galvanic protection, or a combination of these give every indication of a 25 to 50% increase in life. (3) The repair of hard points, using heavier scantlings, using anti-corrosive steel, and using inhibitors might extend the life of cargo spaces beyond 20 years without major bulkhead renewals. (13 references).—L. E. W.

**Experimental Set-Up for Investigating Ash Deposition and Corrosion Phenomena on Gas-Turbine Materials at High Temperatures.** C. Kind. (*Brown-Boveri Rev.*, 1953, **40,** May-June, 196–199). The author describes the effect of fuel ash deposits on machine construction materials and the results of experiments in a test section are illustrated by diagrams and photographs. It was found that certain materials are protected against progressive corrosion by a strong surface layer built up under the influence of the fuel ash and hot gases. With other materials this layer peels off again and corrosion can recommence. Between these two extremes are materials which are subjected initially to corrosion in patches, but whose surface does not corrode any further after a time.—L. E. W.

**The Corrosion of Metals by a Saturated Fuel.** I. N. Putilova, L. G. Gindin, and E. V. Artamonova. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94,** (3), 489–492). [In Russian]. The causes of corrosion of metals by a saturated fuel and particularly by kerosene were investigated. Tests were made by inserting specimens from carbon and low carbon steels and magnesium alloys into kerosene, recording the time of appearance of the first signs of corrosion, and quantitatively analysing the corrosion products. Organic acids formed by the auto-oxidation of kerosene were responsible for corrosion.

Iron seems to stimulate the process of oxidation of kerosene. The usual inhibitor of corrosion of steel in water (sodium benzoate) was inactive in kerosene. Inhibitors for preventing the corrosion of steel in kerosene are the organic compounds belonging to thio-, chlor- and amino-derivatives of fatty and aromatic groups. Some of these, when present in kerosene in amounts of 0·05–0·1%, completely protected steel samples for over a year. These inhibitors prolong the induction period and do not retard the corrosion process like ordinary inhibitors.—V. G.

**Oxidation of Iron in Air at High Temperatures.** V. V. Ipat'ev and V. I. Tikhomirov. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94**, (3), 505–508). [In Russian]. The kinetics of scale formation, its composition and structure were investigated. Kinetics of the process were followed by continuous weighing and the structure and composition of the scale were determined by micrographic X-ray and chemical analysis. Oxidation of Armco iron containing 0·05% of carbon in dry and moist air in the temperature range 380–1034° C. was studied. It was shown that the oxidation in dry air takes place according to the equation $q^2 = kt$, where $q$ = increase of weight in mg./sq. cm., $t$ = time in min., and $k$ = constant characteristic for a given temperature. For practical purposes the equation : $\log q = 3{\cdot}625 - \frac{3916}{T} + \log \frac{t}{2}$ (T = absolute temperature) is proposed. During oxidation above 750° C. the scale consists of three layers : FeO, $Fe_3O_4$ and $Fe_2O_3$ ; during oxidation at temperatures below 570° C. of two layers : FeO and $Fe_3O_4$. The dependence of the composition of scale on the temperature of oxidation is presented in graphical form.—V. G.

**Oxidation of Iron in Steam, Steam–Hydrogen and Steam–Oxygen Mixtures at High Temperatures.** V. I. Tikhomirov, V. V. Ipat'ev, and I. A. Gofman. (*Doklady Akademii Nauk S.S.S.R.*, 1954, **94**, (2), 305–308). [In Russian]. The kinetics of the oxidation of iron in steam were studied in the temperature range 400–1077° C. From the results, an equation is proposed from which it is possible to calculate the amount of oxygen reacting with iron at a given temperature and in a given time interval. The oxidation of iron in steam–hydrogen mixtures ($H_2O/H_2$ = 1·26 ; 1·61 ; 3·16 ; 4·5 ; 6·0 and 10·0) in the temperature range 972–810° C. and in steam–oxygen mixtures (20, 42 and 96 vol.-% of oxygen) at 972° C. were also investigated. When the scale consisted of a wüstite layer alone the velocity of oxidation of iron was strongly dependent on the partial oxygen pressure. This is explained by the assumption that the rate controlling factor is the velocity of diffusion of reacting components through wüstite.—V. G.

**Corrosion and Preservation of Industrial Steelwork.** L. A. Ravald. (*Indust. Finishing*, 1954, **6**, Feb., 508–514, 520–526). After a general survey of corrosion and its effects, the merits and disadvantages are discussed of a number of protective treatments, including temporary protective films, linseed films, painting, phosphatizing, hot-dip galvanizing, metal spraying, and combinations of these. Particular instances are quoted of coatings, and some defects in them, as used for gasholders.—K. E. J.

**Cavitation and Chemical Reactions.** A. Dognon and Y. Simonot. (*J. Chim. Phys.*, 1953, **50**, Feb., 94–96). The relation between chemical reactions under the influence of ultrasonic vibrations and the various factors determining the appearance of cavitation bubbles has been studied. The rate of the reactions investigated increased with rising temperature and decreasing frequency.—A. G.

**The Measurement of Electrode Potentials.** N. Hackerman. (*Corrosion*, 1954, **10**, Feb., 70–72). The preparation and use of the calomel half-cell and of the copper-saturated copper sulphate half-cell are described. For the measurement of the potentials a moving coil voltmeter, a vacuum tube voltmeter, or a potentiometer are suitable. These are also described.

**Fundamental Concepts of Electrode Potentials.** A. J. de Bethune. (*Corrosion*, 1953, **9**, Oct., 336–344). A distinction is made between potential differences observed at metal–liquid interfaces at reversible and at polarized electrodes. There are different thermodynamic principles, which are discussed, governing the two types. A note is included on the American and European conventional signs. The application of cathodic polarization to cathodic protection is discussed. The properties of the electrical double layer at an ideal polarized electrode are surveyed.—J. F. S.

**Interpretation and Significance of Potentials of Metals in Aqueous Solutions.** M. Cohen. (*Corrosion*, 1953, **9**, Oct., 372–376). The potential depends on the reactions at the metal surface and the physical conditions. If corrosion is occurring, the potential measured is not usually an equilibrium one but a mixed polarized potential. This measured potential is a poor criterion of the corrosion resistance. The effect of the resistance paths in the system on the potentials are considered. Examples of the potentials of iron in various systems are given and the main factors determining these potentials are outlined.—J. F. S.

**Current Drainage Survey for Cathodic Protection.** H. M. Powell. (*Corrosion Prevention and Control*, 1954, **1**, Apr., 100–101, 115). The author discusses the principles and considerations involved in the design of a cathodic protection installation. The source of a suitable D.C. supply, the siting of a temporary groundbed, and the cables involved are dealt with briefly and the method of testing the apparatus is described.—L. E. W.

**Study on High Temperature Oxidation of Iron and Its Alloys.** T. Mishima and M. Sugiyama. (*Tetsu to Hagane*, 1950, **36**, May, 184–189 ; June, 263–267 ; July, 317–321 ; Oct. 495–499). [In Japanese]. Limits to oxidation resistance were found at the following temperatures : Armco iron 1350°, Fe–Al alloys 1300°, Fe–Si alloys 1170°, Fe–Al–Si alloys 1150°, and Fe–Cr–Si 1250° C. In Fe–Cr alloys, the oxidation scale was found to consist of five layers, consisting of iron oxides but with $Cr_2O_3$ in the inner layer ; this produces the high oxidation resistance. The composition of the layers in the scale on Fe–Al, Fe–Cr–Al and Fe–Si alloys is also reported ; the inner layers consisted respectively of $FeO(FeAl)_2O_3$, $FeO(Fe, Cr, Al)_2O_3$ and $Fe_2SiO_4$, although $SiO_2$ was produced with the high silicon alloys. Relationships between the thickness of the coating on aluminium-sprayed steel and its life under high temperature oxidizing conditions have been determined.—K. E. J.

**Results of Co-operative Testing Programme for the Evaluation of the Oxalic Acid Etching Test.** M. A. Streicher. (*Amer. Soc. Test. Mat. Bull.*, 1954, Jan., 63–67). The results of a co-operative investigation into the possible use of a rapid electrolytic oxalic acid etching test to supplement the boiling nitric acid test used to measure the susceptibility to intergranular corrosion of stainless type steels, are given and discussed.—B. G. B.

**Electrolytic Etching in Oxalic Acid Used to Screen Cast CF-8 and CF-8M Stainless Steels from the 240-Hr. Nitric Acid Test.** F. H. Beck, N. D. Greene, jun., and M. G. Fontana. (*Amer. Soc. Test. Mat. Bull.*, 1954, Jan., 68–71). A comparison of the boiling nitric acid and electrolytic oxalic acid tests for measuring the susceptibility to intergranular corrosion of cast stainless steels has been made. The rapid oxalic acid method is shown to be capable of eliminating the necessity for the long nitric acid method on all samples.—B. G. B.

**Screening Cast Stainless Steels by Electrolytic Etching in Oxalic Acid.** G. W. Jackson and W. A. Luce. (*Amer. Soc. Test. Mat. Bull.*, 1954, Jan., 71–74). The electrolytic oxalic acid etching test for determining the susceptibility of cast and wrought austenitic stainless steels to intergranular corrosion has been investigated. Appreciable quantities of ferrite in the structure did not affect the use of this test. The oxalic acid method eliminates the need for using the long nitric acid test on all samples.—B. G. B.

## ANALYSIS

**Use of Zinc Oxide Electrodes in the Spectro-Chemical Determination of Special Elements in Steel.** F. Velasco Velasco. (*Inst. Hierro Acero*, 1953, **6**, Oct.-Dec., 351–355). [In Spanish]. A medium type spectrograph is used to determine qualitatively nickel, chromium, molybdenum, tungsten, vanadium, and copper in solutions of various special steels using cup electrodes in the form of zinc oxide briquettes and spark excitation. The aim was to find a practical method for analysing special steels with small and medium equipment.

**Use of Quantometer for Rapid Steel Analysis.** M. F. Hasler and B. R. Boyd. (*Amer. Inst. Min. Met. Eng. Proc. Elec. Furn. Steel Conf.*, 1952, **10**, 143–151). The authors outline the principles of operation of the Production Control Quantometer, and quote analysis results showing the expected precision values for low-alloy and stainless steels. The problem of

slag analysis by the quantometer is briefly considered, and an estimate of costs and savings effected is given.—G. F.

**Qualitative Spectrochemical Analysis.** W. Hartmann. (*Bell Lab. Record*, 1953, **31,** Dec., 470–475). The author discusses broadly the theory, operating principles, and applications of the prism spectrograph. Sample spectra of several elements are given and the qualitative nature of the method is stressed. The 'reference plate' technique used in the Bell Laboratories is described and illustrated.—L. E. W.

**Colorimetric Determination of Acid-Soluble Aluminium in Steel.** M. C. Steele. (*Amer. Foundryman*, 1954, **25,** Jan., 56–57). Details are given of a colorimetric method for determining acid-soluble aluminium in amounts up to 0·02%. After solution of the sample in perchloric acid and separation of the alumina and silica, a mercury cathode separation is carried out to remove the iron. The colour is developed by aluminon after fixing any remaining ferrous ions as a complex with thioglycollic acid.—B. C. W.

**Rapid Photometric Determination of Cobalt in the Presence of Iron.** J. N. Pascual, W. H. Shipman, and W. Simon. (*Anal. Chem.*, 1953, **25,** Dec., 1830–1832). The determination of cobalt by the use of the nitroso-*R* salt is simplified in the presence of iron by additions of alkali fluorides. When these are present the working curves conform very closely to Beer's law either in the presence or absence of iron.—A. G.

**On the Rapid Determination of Mn in Iron and Steel by $(NH_4)_2S_2O_8$–$As_2O_3$ Method. (I).** K. Hosoda and K. Kawamura. (*Tetsu to Hagane*, 1950, **36,** Dec., 618–621). [In Japanese]. To eliminate defects due to analytical error, every step in the determinations had been examined, and recommendations are made for the conditions to be observed.

**The Determination of Sulphur in Malleable Iron by Combustion in a Stream of Oxygen.** J. Scheunemann. (*Met. u. Giesserei Techn.*, 1954, **4,** Mar., 125). The 0·5-g. sample is placed in a china clay crucible and positioned, by means of the combustion tube, in the centre of the furnace. The sample is heated almost to combustion temperature, and dried oxygen is then passed over it. Examples of analyses are given, and the apparatus is described in detail.—L. J. L.

**Determination of Magnesium in Nodular Cast Iron.** R. Suarez Acosta. (*Inst. Hierro Acero*, 1953, **6,** Oct.-Dec., 401–406). [In Spanish]. The author discusses the determination of magnesium in castings after the iron has been separated by ethyl ether in a continuous extractor.—R. S.

**Determination of Hydrogen in Liquid Steel.** Dauvergne. (*Centre Doc. Sid., Circ. Inform. Tech.*, 1953, (5), 823–828). A simple thick-walled Pyrex apparatus with only three rubber joints was employed for vacuum degassing at 600° C. The defects attributable to hydrogen in steels are described with particular reference to the manufacture of tubes from chromium steels.—A. G.

**Acoustic Methods for Gas Analysis.** L. E. Lawley. (*Chem. Indust.*, 1954, Feb. 20, 200–203). A brief account is given of methods of analysing gas mixtures which are based on measurement of the velocity of sound in a gas. A description is also given of an apparatus employing a phase shift method. Possible applications are outlined.—R. A. R.

**Use of Hot Concentrated Phosphoric Acid in Rapid Analysis of Ferro-Chromium and Ferro-Vanadium.** T. Ikegami and N. Nagaoka. (*Tetsu to Hagane*, 1950, **36,** June, 279–282). [In Japanese]. Details are given of a procedure for the analysis of high-carbon ferro-alloys not soluble in the normal acid mixture. Chromium in ferrochromium can be determined in 20–23 min., and vanadium in ferrovanadium in 14 min.—K. E. J.

**International Methods of Coal Analysis.** J. G. King. (*Coke Gas*, 1954, **16,** Feb., 55–60). An account is given of the progress achieved at the November 1953 meeting of Technical Committee 27 of the International Organisation for Standards, which body is concerned with the formulation of agreed methods of analysis and sampling of solid fuel. Among the methods of coal analysis under study are those for moisture content, ash, volatile matter, calorific value, caking and swelling power, sulphur, nitrogen, phosphorus, chlorine, and arsenic.—B. C. W.

**Determination of Naphthalene in Wash Oil and Coke-Oven Gas.** N. J. Klein and G. W. Struthers. (*Analy. Chem.*, 1953, **25,** Dec., 1818–1821). The development of a spectrophotometric method to replace picrate methods of naphthalene determination is described. Concentrations down to 0·001% can be measured with a relative accuracy of 0·5%.—A. G.

**X-Ray Method for the Quantitative Determination of Mullite in Refractories.** (*Prace Instytutow Ministerstwa Hutnictwa*, 1954, **6,** (6), 314–321). [In Polish]. An X-ray powder method for the quantitative determination of mullite in refractories is described. As a reference material, a 10% addition of sodium chloride was used. Intensity measurements were made on lines, $d = 2{\cdot}20$Å for mullite (121) and $d = 1{\cdot}99$Å for sodium chloride (220). Possible sources of error are discussed. The relative error for mullite concentrations between 20 and 80% was estimated to be of the order of 14%.—V. G.

## ECONOMICS AND STATISTICS

**Mining Statistics 1946–50.** R. Falck-Muus. (*Tidsskr. Kjemi, Bergvesen Met.*, 1954, **14,** Jan., 7–13; Feb., 25–36). [In Norwegian]. Statistics on the production of minerals in Norway for each of the years 1946 to 1950 are presented.

**The Italian Market for Stainless Steels.** (*Acciaio Inossid.*, 1954, **21,** Jan.-Feb., 3–14). [In Italian]. A detailed account is given of the market conditions for stainless steels in Italy—actual and projected. Statistical information is supplied giving production and consumption figures for different regions in the country.—M. D. J. B.

**Impressions Gathered During a Visit to the U.S.A. on American Fuel Economy and Plant Management.** F. Wesemann. (*Stahl u. Eisen*, 1954, **74,** Mar. 11, 321–328). The author discusses the social, economic, and raw materials and fuels background of the high productivity in the steel industry of the U.S.A. and then compares the size, charge weight, output, and fuel consumptions of American blast-furnaces and open-hearth furnaces with those in Europe.—J. P.

**Capacities in a Manufacturing Process.** R. Solt. (*Operational Res. Quart.*, 1954, **5,** Mar., 24–26). The author discusses steelmaking as an example of a manufacturing process in which capacities play an important part. The difficulties arising from combined batch and continuous processes and the methods of overcoming them are indicated. It is concluded that the economic optimum is reached when the marginal cost of making the system more efficient is equal to the marginal return which results from this increased efficiency.

**Strategic Materials.** D. F. Green. (*Trans. Australian Inst. Metals*, 1952, **5,** 43–46). The author broadly outlines some details of the international allocation of materials at present in short supply as between the free countries of the world, and shows the part played by Australia. The materials discussed are copper, zinc, lead, tungsten, molybdenum, cobalt and nickel, and their compounds, ores and concentrates. The author considers briefly the conservation of raw materials in short supply.—L. E. W.

**Heavy Engineering Industries of Japan with Special Reference to Iron and Steel.** P. Kutar. (*Indian Inst. Metals, 7th Annual General Meeting*, Calcutta, 1954, Feb. 6, 1–11). The author describes the condition of the steel industry and the possibility of manufacturing mechanical and electrical equipment for the industry in the Japanese engineering workshops. The economic and sociological backgrounds to the Japanese heavy engineering and steel industries are discussed and some details are given of the consumption of iron ore and coal and the amounts imported.—L. E. W.

**Japan's Iron and Steel Industry.** C. Verity. (*Tetsu to Hagane*, 1950, **36,** July, 328–330). [In Japanese]. A general economic survey of the industry is made; for progress, waste must be reduced, quality improved, costs lowered, and improved coal mining and blending methods introduced.

**Application of Research to an Industry Composed of Small Firms.** C. N. Kington. (*Metal Treatment and Drop Forg.*, 1953, **20,** Dec., 597–603). The application of research to a small-firm industry is a difficult matter involving many problems from financial, technical, and human viewpoints. The author attempts to analyse the situation, and discusses means of overcoming some of the difficulties.—P. M. C.

**The Organization of Cost Accounting in a Swedish Iron and Steel Works.** N. Wadstein. (*Stahl u. Eisen*, 1954, **74,** Feb. 25, 285–287).

**Maintenance in Iron and Steel Works and Its Effect on Costs.** K. H. Hüser. (*Stahl u. Eisen*, 1954, **74,** Jan. 1, 1–9). The importance of timely maintenance in reducing operating costs is stressed. Some general guidance is given for planning repair and maintenance work to save unproductive time. The economies made possible by reconstruction are discussed.

## MISCELLANEOUS

**Developments in Communications.** W. M. Martin. (*Iron Steel Eng.*, 1954, **31,** Feb., 95–98). The author makes a survey of the development of the telephone, very high frequency radio and other systems for improving communications in industry.—M. D. J. B.

**Some Aspects of the Design of V.H.F. Mobile Radio Systems.** E. P. Fairbairn. (*Proc. Inst. Elec. Eng.*, 1954, **101,** Part III, Mar., 53–68).

**Consett Iron Company Limited: Transport Services.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 87–88). A brief account is given of the transport services at the Consett Iron Co. Ltd. The operating staff, the handling of inward and outward traffic, wagon standage and siding accommodation, and internal haulage, are dealt with.—G. F.

**Consett Iron Company Limited: Technical and Research Department.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 89–92). Details are given of the layout, equipment, and internal organization of the Technical and Research Department of the Consett Iron Co. Ltd. An account of its work is given, with particular attention drawn to the chemical and metallurgical, refractories, and instruments sections.—G. F.

**Consett Iron Company Limited: Training and Welfare.** (*Iron Coal Trades Rev., Special Issue*, 1954, **168,** Mar. 1, 95–96, 104). A brief account is given of the training and welfare schemes at the Consett Iron Co. Ltd. The selection and recruitment of personnel, and accident prevention measures, are also discussed.—G. F.

**Industry and Education.** H. W. Jones. (*Amer. Iron Steel Inst., Regional Tech. Meetings*, 1953, 1–8).

**Iron and Steel in Education.** B. R. van Leer. (*Amer. Iron Steel Inst., Regional Tech. Meetings*, 1953, 211–216).

**The Professional Education of Apprentices in Industry.** G. Laurisch. (*Stahl u. Eisen*, 1954, **74,** Feb. 11, 219–222). The fundamental principles and functions of an industrial training scheme and the importance of professional education to the well-being of the firm and to the national economy are discussed.—J. P.

**How to Make Sure Your Slings Are Safe.** W. C. Richards. (*Foundry*, 1954, **82,** Jan., 137–138). The stresses in a wire rope sling for a given load depend on the angle at which the legs are used. A chart and table are given from which either the rated capacity of a given sling or the correct diameter of rope to use for a given load can be calculated.—B. C. W.

**Cooling Pond May Answer Your Water Cooling Problem.** J. W. Langhaar. (*Chem. Eng.*, 1953, **60,** Aug., 194–198). Cooling ponds may be preferable to other methods of water cooling, particularly where water is scarce or the problem of contamination arises. Nomograms are given and their use described for determining pond size for a specific cooling load under any atmospheric conditions.—A. G.

**Know Your A, B, C's—of Government Specifications.** A. G. Gray. (*Steel*, 1954, **134,** Jan. 18, 100–103). The principles of the U.S. Government's Federal and Military specifications systems are explained. Identification of items is by groups of letters followed by a specific code number.—D. L. C. P.

# BOOK NOTICES

Hume-Rothery, William, and G. V. Raynor. "*The Structure of Metals and Alloys.*" Institute of Metals Monograph and Report Series, No. 1. Third edition. 8vo, pp. viii + 363. Illustrated. London, 1954 : Institute of Metals. (Price 35*s.*, $5.50)

The publication of the first edition of this book, in 1936, opened up a whole new world to the metallurgist. It was so completely different from all books on physical metallurgy then available. Different not merely in its subject matter but, and much more important, in its revolutionary approach to the subject. For the first time it was possible to see something of the way in which metallurigcal structures and properties are determined by those of the component atoms. Furthermore, the book also showed that the prospect of being able to design alloys with specific properties, by assembling together the right atoms in the right arrangements, was certainly no longer a mere dream, even though its full realization was still far off. At a cost of only 4*s.* 6*d.* such enlightenment was almost miraculous.

The price of the book has risen since then, but by no more than is appropriate in view of the expansion of this field of knowledge over the past 18 years. To help deal with the task of assembling the immense number of observations into a coherent scheme, in this third and greatly enlarged edition of the book, Dr. Hume-Rothery has joined forces with his long-standing colleague, Professor Raynor. With two such authorities in command one is inclined to take the standard of excellence maintained throughout the book almost for granted, but special mention must be made of the thoroughness with which every aspect of the subject is covered, of the critical and authoritative nature of the account, and of the masterly way in which the authors make significant comparisons between apparently unrelated crystal structures and types of phase equilibria.

The main impression one gets of the development of the theory of alloys, by comparing this edition with the first, is that not many new principles have been developed in the intervening years but, instead, those principles originally worked out on the copper- and silver-based alloys have since been used repeatedly and successfully to open up vast new territories in other parts of the alloy field. The criticism that was sometimes, and in my opinion most perversely, made of the theory of alloys as presented in the first edition, to the effect that it dealt only with a small class of alloys, cannot possibly be maintained in the face of the broad coverage given in this edition.

Alloys based on aluminium, magnesium, and titanium, as solvents are now scrutinized in detail, and a fascinating picture is built up of the operation in these alloys of the atomic size and valency factors, sometimes working together and sometimes working one against another. Many of the complexities in these and other alloy systems are rendered understandable by this appreciation of the effects of several factors operating simultaneously. Practically everything useful that has been said about the structure and properties of transitional metals and their alloys is gathered together in the book, and the alloys of iron have been given an entire chapter of their own, which includes such topics as the theory of phase equilibria in these alloys, the isothermal transformation curve, the structures of carbides, and the forms of graphite in cast iron. Intermediate phases are considered in another chapter, which includes a discussion of the sigma phase in alloys of transitional metals, and a survey of Laves phases which suggests that we are now near to the discovery of an important generalization about the structure of many classes of alloy phases. In the final chapter of the book a different aspect of crystal structure, that of imperfections in crystals, is taken up, and topics such as polygonization, twinning, lattice vacancies, and dislocations are introduced in an elementary and readable account of the recent advances in this field.

In conclusion, the reviewer is quite sure that this edition of the book will fire the imagination of the student of today as much as did the first edition those of us who were students 18 years ago. To the practising physical metallurgist, already acquainted with the earlier editions, it is hardly necessary to say that he cannot afford to be without a copy of this edition; he will surely know this already.

A. H. Cottrell.

Institution of Metallurgists. "*The Microscopy of Metals.*" Lectures delivered at the Institution's Refresher Course 1953. 8vo, pp. 132. Illustrated. London [1954] : The Institution. (Price 15*s.* 6*d.*)

To cover a subject of the magnitude of microscopy in the course of 132 pages is no mean task, yet in this volume the authors have succeeded in presenting a comprehensive review of the present position in this field. Almost every phase of the subject is mentioned and both new and old techniques receive attention. Considering the wide range of topics under discussion it is inevitable that some subjects should be disposed of in a few words; adequate compensation for this is to be found in the numerous references quoted.

The first two papers are of a general nature. Conn discusses microscopes and microscopic techniques, including optical, electronic, ultrasonic and radiographic methods. Evans deals with conventional methods employed in metallography and gives numerous examples of their application.

Turning to more specialized aspects, Mott gives an account of the rôle of polarized light in metallography, whilst Forsyth discusses hot-stage microscopy. The final paper, by McLean, is concerned with phase contrast and interference microscopy.

Each of the papers gives a good account of the subject concerned, and the authors are careful to consider the various topics not as isolated subjects, but in relation to the general field of metallography. The amount of theory given is kept to a minimum and is of a comparatively simple nature ; this, together with the preservation of the style of the original lectures, renders the book extremely readable. The volume should be of value to every metallurgist, either in its intended rôle of a refresher course or as a guide to the student. Its value as a reference book could have been enhanced by the inclusion of an index, although this is perhaps unusual in a work of this nature.

It is regrettable that some of the otherwise excellent photomicrographs have suffered owing to the method used for reproduction, as is the fact that one or two typographical errors have appeared.—G. HOYLE.

JOHANNSEN, OTTO. "*Geschichte des Eisens.*" Dritte völlig neu bearbeitete Auflage. La. 8vo., pp. [vii +] 622. Illustrated. Düsseldorf, 1953 : Verlag Stahleisen. (Price DM 75.–)

This new and revised edition of the author's book, which was originally published in 1924 and was at that time more or less a summary of Professor Ludwig Beck's voluminous " Geschichte des Eisens." is greatly enlarged in comparison with the two previous editions. It has also been brought up to date, though this applies mainly to matter concerning Germany, Austria, and the Scandinavian countries. The early historical development in other iron-producing countries appears to receive much less attention ; it would seem that the author did not consult the work of B. Gille on "*Les origines de la grande industrie métallurgique en France,*" Paris, 1948, for had he done so he could have presented a more complete and accurate history of the French iron industry.

Some of the author's statements about the early iron industry in England will not find universal acceptance. The reviewer is unaware of any foundation for the assertion (p. 274) that Germans were active in the English iron industry before 1300, nor of any evidence that the special type of furnace termed " *Flossofen* " in German, which produced iron in liquid form and was in use mainly in Germany and Austria, was ever introduced into England (p. 144).

The more modern history of iron-making is dealt with much more completely, in particular, the eighteenth and nineteenth centuries, for which an abundant literature is available. It is unfortunate, however, that no biographical notes are supplied, for this makes the book difficult to use for research purposes ; the idea that the reader should enquire at Düsseldorf for such material is rather unusual.

Despite the above criticisms, the reviewer recommends the student of the history of iron-making to study this book. The illustrations are indeed excellent ; their abundance—their number has been almost doubled in this new edition—and quality give the book a value which is quite outstanding.—H. R. SCHUBERT.

ZWIKKER, C. " *Physical Properties of Solid Materials.*" La. 8vo, pp. viii + 300. Illustrated. London, 1954 : Permagon Press. (Price 60*s.*)

This book sets out to summarize the entire field of solid-state physics and is intended to be read by those engaged in branches of the physical sciences, including engineering. In a book of this kind it is not relevant to comment on the actual subject matter included, for this is essentially a review of current knowledge drawn from many sources, of which the author's own contributions cover a very small fraction. One can only discuss the presentation, adequacy of the subject matter, and possible scope of usefulness. Both theory and experimental results are treated throughout, but experimental methods are omitted. Fourteen chapters amply illustrated with very clear line drawings and photographs cover all aspects of the subject.

The book begins with atomic theory and crystal structure. Heterogeneity and anisotropy are then dealt with together with the subjects of elasticity and plasticity. The second half of the book covers thermal properties, transformations, porosity, and ferromagnetism, concluding with the electronic and surface properties of solids. The book shows no particular bias, either to metals or to non-metals, both being covered quite impartially. It is unfortunate that the subjects of such great technical importance to the engineer and metallurgist as fatigue and creep are dealt with summarily, the treatment of these combined subjects covering less than three pages. As this book claims to review existing knowledge, the failure to treat these two subjects adequately is difficult to understand. Stress relaxation and recovery are also dealt with far too briefly. In all these fields the literature is vast, with regard to both theoretical and experimental work. In a book of only 300 pages covering such a wide field, some aspects of the physical properties of solids inevitably would be treated briefly. Partly offsetting this criticism there are numerous references to published work given conveniently at the foot of each page where a reference occurs in the text. The chapter on elastic after-effect and damping is very good indeed, in effect constituting a first-class review of Zener's classic book on this subject. Dislocation theory is adequately introduced and many references to the recent work on this subject are provided. The later sections on the thermal, electronic, and magnetic properties of solids are also extremely good.

The book is clearly written and very readable. The author's claim to dispense with lengthy mathematical discussion and concentrate on clarity and conciseness is fully justified. This book will have its greatest value for the student and post-graduate worker in physics and metallurgy, while physical chemists and engineers will also find information of use to them, but its value for the full-time research worker is likely to be very limited.—J. SAVAGE.

## NEW PUBLICATIONS

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